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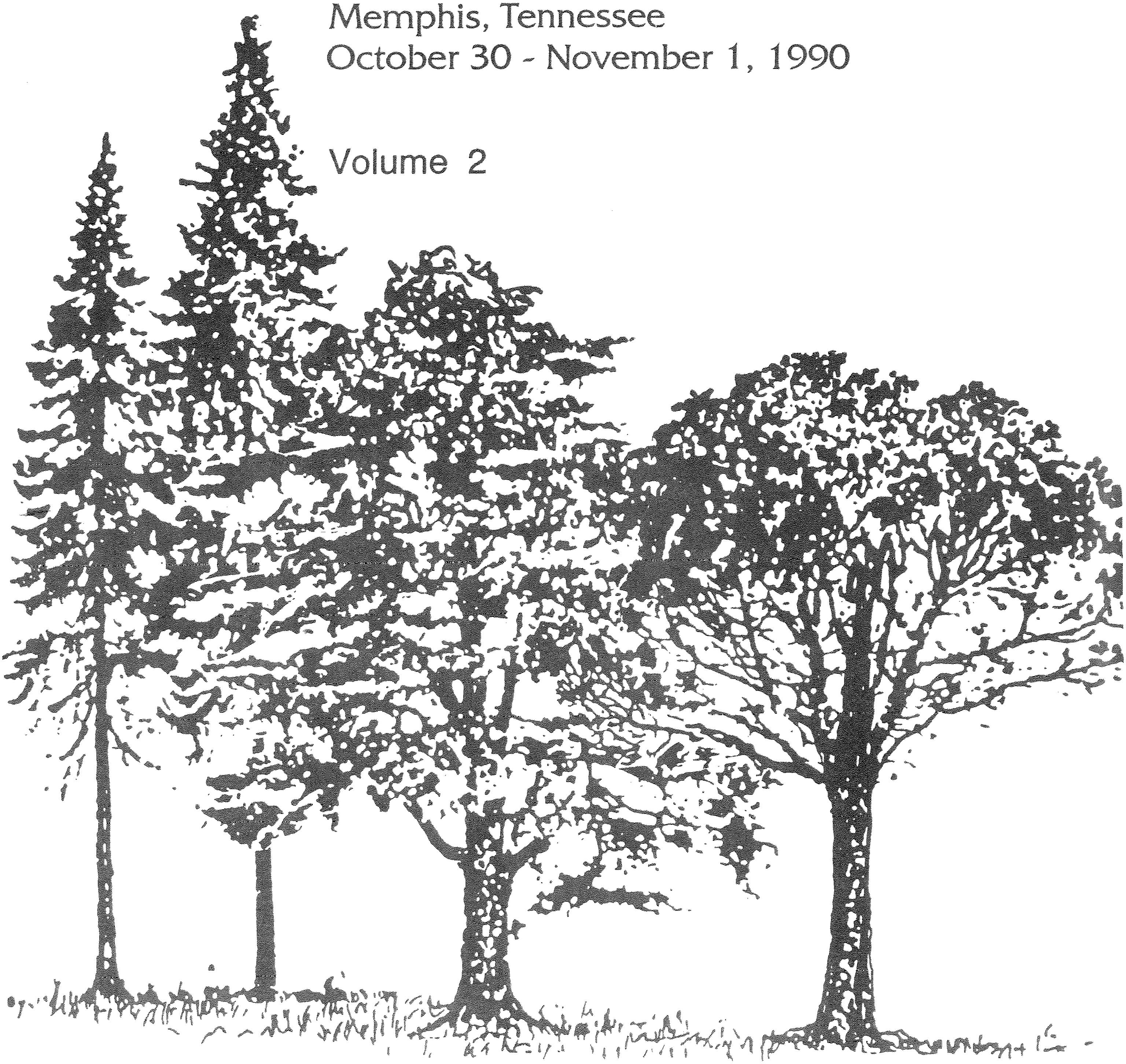

Proceedings of the Sixth Biennial Southern Silvicultural Research Conference

Volume 2

Compiled and edited by
Sandra S. Coleman and Daniel G. Neary

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EFFECT OF GLOMUS SPP. ON THE GROWTH OF EASTERN COTTONWOOD CUTTINGS [1]

Mary Anne Sword, Joan P. Smith, and Harold E. Garrett [2]

Abstract. The rapid juvenile growth of eastern cottonwood (Populus deltoides Bartr. ex Marsh.) makes it a desirable hardwood species for revegetation of disturbed sites. In addition, revegetation may be facilitated by improved root growth in response to endomycorrhizal colonization. An experiment was conducted to identify the effect of inoculation with a mix of three Glomus spp. isolates on the root growth rate of eastern cottonwood cuttings. Results indicated that endomycorrhizal colonization of eastern cottonwood cuttings was successful using commercial endomycorrhizal spore inoculum. However, endomycorrhizal inoculation appeared to have a negative effect on growth during greenhouse production. Factors contributing to this response are discussed. Reduced root growth rate in response to endomycorrhizal inoculation, but lack of either shoot or root dry weight response, suggests that endomycorrhizal inoculation may have affected root system morphology.

Introduction

Benefits derived from endomycorrhizal associations have been documented for many hardwood tree species (Pope 1980; Kormanik et al., 1982; Melichar et al., 1986). In addition to modification of shoot growth, endomycorrhizal colonization may result in physiological and morphological alteration of root development. This potential influence of endomycorrhizal fungi on hardwood root systems may lead to improved survival and growth following outplanting of seedlings and cuttings.

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Past research has suggested that endomycorrhizal symbiosis may modify root morphological features such as the number of lateral roots and root hairs, total root length and root dry weight (Kormanik 1985, Berta and Gianinazzi-Pearson 1986, Dixon 1988, Simmons and Pope 1988). The rate of root elongation, another aspect of root development which may be important to seedling survival and growth, may be characterized by a greater increase in mycorrhizal than in nonmycorrhizal plants.

An increase in root elongation rate would be beneficial following outplanting of hardwood species which are relatively intolerant of moisture stress. Eastern cottonwood (Populus deltoides Bartr. ex Marsh.) possesses rapid juvenile growth making it an excellent choice for use in revegetating disturbed sites. Unfortunately, this species is relatively intolerant of moisture stress. This was exemplified by

Blake et al. (1984) who compared the water use efficiency (WUE) and dry matter production of 17 Populus spp. clones. Results indicated that eastern cottonwood ranked only tenth in WUE and possessed the lowest biomass production rate when compared to the remaining 16 clones tested. Endomycorrhizae could prove advantageous to drought-intolerant species such as eastern cottonwood and provide a growth advantage on sites with adequate fertility but inadequate moisture.

Objectives of this study included the synthesis of endomycorrhizal eastern cottonwood cuttings using a commercial spore inoculum mix of three Glomus spp. isolates. Subsequently, effects of endomycorrhizal inoculation on shoot growth and root development of greenhouse-grown eastern cottonwood cuttings were evaluated.

Materials And Methods

Clear acrylic tubes, 61.0 cm in length and 7.6 cm in diameter, were covered at the base with 0.5 cm^2 aluminum mesh. Washed gravel was placed in tubes to an approximate depth of 5 cm. Subsequently, 6.3 L of uninoculated or inoculated growth medium was poured into tubes resulting in approximately 10 cm of unoccupied depth at the top of tubes. The growth medium of uninoculated and inoculated tubes consisted of 1:1:2 (v/v/v) sandy loam soil-peat-perlite which was sterilized with methyl bromide. The growth medium of inoculated tubes contained, in addition, a 15-ml volume of spore inoculum of each of three isolates of Glomus spp. As a result, approximately 15 thousand spores of Glomus spp., isolates 10 (Imperial Valley, CA), 25 (Vetura/Oxnard Plain, CA) and 71 (Midwestern U.S.) (Native Plants Inc., Salt Lake City, UT), were thoroughly mixed throughout the growth medium of each inoculated tube providing an inoculation intensity of 7.1 spores/ml of growth medium (8.2 spores/g).

Dormant eastern cottonwood cuttings from a single selection (miscellaneous Missouri selection, GG-1) were obtained from the George 0. White State Forest Nursery in Licking, Missouri, in April 1989. Cuttings were divided into apical, middle, and basal segments, each 20.3 cm in length. Cutting segments were planted vertically in tubes to a 10-cm depth. With the exception of the most terminal intact bud, aboveground lateral buds were excised. To facilitate adventitious root growth along the lower surface, tubes were placed at a 45° angle, 46 cm apart, on greenhouse benches. Sides of tubes were covered with black plastic to create a dark rooting environment. Black plastic was then covered with white cotton sheeting to reduce temperature fluctuation of the rooting environment.

Eastern cottonwood segments were watered when the growth medium appeared dry. Four weeks following bud break, fertilization began. Segments were fertilized weekly with 0.5 L of %-strength Hoagland's solution (Bonner and Galston 1952) throughout the 26-week cultural period. Natural lighting was utilized. Ambient greenhouse temperature ranged from 20 to 32°C.

A randomized complete block design with three blocks was used. Treatments were noninoculation or inoculation with a Glomus spp. mix (three isolates of *Glomus* spp., species unknown). Blocks represented the location of 20.3-cm segments within the original dormant cutting (i.e., apical, middle, and basal segments). Three replications of apical, middle, and basal 20.3-cm cutting segments received either no inoculation or inoculation with *Glomus* spp. and were randomly placed on greenhouse benches.

The gravitropic response of roots as well as the acrylic nature of tubes allowed root growth to be monitored throughout the cultural period. Growth increments were drawn on lower surfaces of tubes at approximately 2-day intervals with permanent marking pens. Following termination of the greenhouse phase of the experiment, marked increments were used to calculate root growth rates.

Cuttings were harvested following a 26-week cultural period. Stem length and diameter were measured following 13 weeks of growth and after harvest. Leaf surface area (Li-3000, Li-Cor Inc., Lincoln, NE) as well as root, stem and foliar dry weights (72 h, 77°C) were measured after harvest. Stem length was defined as shoot height from location of shoot emergence on the cutting segment to shoot tip. Stem diameter was defined as the diameter of the stem, 12.7 cm from the location of shoot emergence on the cutting segment.

Following harvest, a 2.0-g subsample of fresh root tissue was randomly selected from the fine roots of each cutting. Endomycorrhizal colonization was evaluated after clearing and staining roots with acid fuchsin (Kormanik and McGraw 1982). Percentage of root length infected and the number of vesicles per cm of root were estimated using the procedure of Giovannetti and Mosse (1980).

Analysis of variance was utilized for determination of relationships between inoculation with *Glomus* spp. and shoot and root development of eastern cottonwood cuttings. Differences between treatment means were tested at $P \leq 0.05$ and $P < 0.10$ using the least significant difference (LSD) test.

Results

Following the 26-week cultural period, inoculated eastern cottonwood cuttings were heavily colonized (63 percent $\pm$ 6 percent; 1.8 vesicles/cm root) with *Glomus* spp.; while uninoculated cuttings were less than 1 percent colonized.

Despite high levels of colonization, endomycorrhizal inoculation had no significant effect on stem length, stem diameter, or on stem, root, or foliar dry weights of eastern cottonwood cuttings (Table 1). The leaf surface area of inoculated cuttings was significantly less than that of uninoculated cuttings (Table 1). Moreover, the daily root growth rate of cuttings during the initial 13-week cultural period was significantly reduced by inoculation (Table 2). Rate of root growth during the last 13-week portion of the 26-week cultural period was not significantly affected by inoculation treatment.

Table 1. **Effect of a mixture of three *Glomus* spp. isolates on the growth of eastern cottonwood cuttings following a 26-week greenhouse cultural period.**

Variable	Treatment	
	Uninoculated	Inoculated
Stem length (cm)	93.4 a *	89.0 a
Stem diameter (mm)	14.6 a	13.6 a
Shoot dry weight (g)	15.2 a	13.9 a
Root dry weight (g)	11.0 a	11.9 a
Foliar dry weight (g)	23.6 a	21.6 a
Leaf surface area (cm*)	3697.8 a	3378.7 b

* Means within a variable followed by the same letter are not significantly different at P $\leq$ 0.05 using the LSD test.

Table 2. **Effect of a mixture of three *Glomus* spp. isolates on the root growth rate of eastern cottonwood cuttings throughout the initial 13 weeks of a 26-week greenhouse cultural period.**

Growth interval	Treatment	
	Uninoculated	Inoculated
(wk)	------------- (cm)	--------------
o-3	....	....
3-5	0.94 a *	0.88 a
5-7	1.00 a	0.80 b
7-9	0.90 a	0.81 a
9-11	0.60 a	0.40 b
11-13	0.26 a	0.12 a
3 - 13 .	0.74 **a**	**0.60 b**

* Means within a growth interval followed by the same letter are not significantly different at P $\leq$ 0.10 using the LSD test.

Discussion

Past research has reported the synthesis of mycorrhizae on eastern cottonwood seedlings (Vozzo and Hacskaylo 1974) and cuttings (Lodge 1989) using field soil containing both endomycorrhizal and ectomycorrhizal fungal inocula. In this experiment, we successfully synthesized endomycorrhizal eastern cottonwood cuttings using commercial endomycorrhizal spore inoculum. Shoot and root growth were either unaffected or inhibited due to endomycorrhizal inoculation.

Many studies have shown that endomycorrhizal colonization stimulates growth of greenhouse-grown hardwood species (Pope 1980; Kormanik et al., 1982; Kormanik 1985; Melichar et al., 1986; Dixon 1988). Furthermore, Navratil and Rochon (1981) demonstrated that, although ectomycorrhizae did not develop on root systems, inoculation with Pisolithus tinctorius [(Pers.) Coker & Couch] resulted in enhanced shoot and root growth of cuttings of four Populus spp. hybrids. However, our results are similar to those of others (Snellgrove et al., 1982; Hselova et al., 1989) in which potential benefits associated with endomycorrhizal inoculation were not expressed in plant growth measurements during the production phase. Negative root growth rate and leaf surface area responses of endomycorrhizal cuttings were observed in this study and may be attributed to a combination of factors.

The physiology of hardwood cuttings may provide some explanation for the growth inhibition observed. Nanda et al. (1971) reported the importance of having adequate exogenous glucose, in addition to indoleacetic acid, for rooting of Populus spp. cuttings. It was reported that a proper balance of nutritional and regulatory compounds determines the rooting ability of this genus. The rapid rate of shoot growth of cuttings when compared with that of seedlings suggests that starch availability for initial root growth may be more limiting in cuttings than in seedlings. Furthermore, the shoot growth rate of cuttings compared to seedlings suggests that production of growth regulators in shoot meristematic tissues may be greater in cuttings. As a result, growth responses of cuttings and seedlings inoculated with endomycorrhizal fungi may differ.

Energy for early shoot and root growth of cuttings is supplied by starch stored within upper and lower portions of the cutting, respectively (Okoro and Grace 1976). Root growth of cottonwood cuttings has been associated with both the initial starch concentration as well as the rate of starch utilization within the lower portion of the stem (Tschaplinski and Blake 1990). This information is supported by Fege and Brown (1984) who found that rooting of Populus spp. cuttings was directly related to size of cutting. Harley and Smith (1983) suggested that negative effects of endomycorrhizal inoculation on plant growth may occur when the intensity of infection is high. In the current experiment, respiration attributed to endomycorrhizal fungus metabolism may have reduced the availability of starch for root growth and subsequently reduced root growth.

Greenhouse environmental conditions may have also contributed to nutritional stress leading to negative growth responses of inoculated cuttings.

Okoro and Grace (1976) attributed low rates of photosynthesis by two species of *Populus* spp., in part, to low irradiance during greenhouse production. They reported that the rate of photosynthesis of *Populus* spp. was only one-tenth that obtained by Regehr et al. (1975) in which cuttings were grown under 1600 uE m^{-2} s^{-1} photosynthetically active radiation (PAR), which represented 90 percent of the PAR necessary for maximum photosynthesis. In the current experiment, maintenance of PAR at 400 uE $^{-2}$ s^{-1} may have been inadequate for maximum growth of eastern cottonwood cuttings, especially those colonized by endomycorrhizal fungi. Again, limited availability of photosynthate for root growth, due to higher metabolic requirements of plants with endomycorrhizal fungal associates than without, may have contributed to reduced growth of the host.

Furthermore, competition between endomycorrhizal fungal isolates may have played a role in the negative growth observed. Lopez-Aguillon and Mosse (1987) demonstrated the negative effect of competition between two endomycorrhizal species on the shoot growth of sorghum (*Sorghum vulgare* Pers.). Following a 5-month cultural period, sorghum plants inoculated with *Gigaspora margarita* (Becker and Hall) and *Glomus fasiculatum* (Thaxt.) Gerd. and Trappe were 60-80 and 80-90 percent infected, respectively; whereas, those inoculated with both *G. margarita* and *G. fasiculatum* were 10-15 percent and 60-70 percent infected, respectively. In association with this competition was an approximate 28 percent decrease in sorghum shoot dry weight.

Similar results were obtained by Lopez-Aguillon and Mosse (1987) with white clover (*Trifolium repens* L.). Following a 4-month cultural period, white clover inoculated with *G. margarita* or *G. fasiculatum* was 45-60 percent infected. However, white clover inoculated with both *G. margarita* and *G. fasiculatum* was 10-40 and 17-35 percent infected by *G. margarita* and *G. fasiculatum*, respectively. Shoot dry weights of plants inoculated with either *G. margarita*, *G. fasiculatum* or the two in combination were approximately 0.82, 0.80, and 0.55 g/pot, respectively. Moreover, root lengths of plants inoculated with either *G. magarita*, *G. fasiculatum* or both were 661, 663, and 410 cm, respectively: In the current experiment, shoot and root growth of eastern cottonwood cuttings may have been reduced due to effects of competition between two or more endomycorrhizal isolates as has previously been reported.

The effect of endomycorrhizal colonization on the nutrition of the eastern cottonwood cuttings during early root development and the effect of competition between endomycorrhizal isolates, in combination with low greenhouse light conditions, may explain the unexpected decrease in growth of inoculated cuttings in this study. However, observations during greenhouse production may not be a good indication of the growth potential of inoculated eastern cottonwood cuttings following outplanting. A benefit which may have been enhanced by endomycorrhizal colonization but not manifested in shoot and root growth measurements is an alteration of root morphology. In the current experiment, significant reduction in root growth rate during the initial 13 weeks of growth, but the lack of a significant effect on root dry weight following the 26-week cultural period, suggests that endomycorrhizal inoculation may have had an early effect on adventitious root system morphology. These potential changes could be beneficial to water and nutrient uptake following outplanting. Further analysis of data collected and additional testing will be necessary to identify such changes and their benefit to outplanting stock.

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MORPHOLOGY, GAS EXCHANGE, AND CARBON-14 ALLOCATION PATTERNS IN ADVANCE CHERRYBARK OAK REPRODUCTION--PRELIMINARY RESULTS [1]

Brian R. Lockhart, John D. Hodges, John R. Toliver, and Bob L. Karr [2]

Abstract. Growth and development of advance cherrybark oak (*Quercus pagoda* Raf.) reproduction was evaluated following seedling clipping and midstory removal. After two growing seasons, released-clipped cherrybark oak seedlings had greater height growth, root-collar diameter growth, and more terminal flushes than true seedlings . No differences were found in the carbon-dioxide exchange rate between true and clipped seedlings although clipped seedlings had a greater rate of stomata1 conductance. One growing season after treatment, clipped seedlings also showed a greater retention of current photosynthates in the shoot as compared with true seedlings. Little difference in patterns of carbon allocation existed among treatments after the second growing season. Results indicate that clipping of cherrybark oak seedlings, in combination with midstory and understory competition control, increases the growth and vigor of cherrybark oak reproduction after two growing seasons.

Introduction

Problems in naturally regenerating oaks occur because of: (1) a lack of a sufficient number of stems as advance reproduction (Beck 1970, Janzen and Hodges 1985); (2) the inability of those stems present to rapidly respond to an increase in resources, mainly light (Johnson 1979, Janzen and Hodges 1987); and (3) a lack of knowledge concerning the basic biology of oak seedlings (Hodges and Janzen 1987, Crow 1988). Several field studies have concluded that between 990 and 1075 seedlings and saplings per hectare (400 and 435/ac) are necessary for adequate stocking of advance oak reproduction (Arend and Scholz 1969; Sander et al., 1976). Other studies, based on stand development research, have concluded that only 110-150 well-spaced oak seedlings per hectare (45 to 60/ac) represent adequate stocking (Oliver 1978, Clat terbuck and Hodges 1988, Kittredge 1988). The differences among "adequate" stocking values are due to differences concerning oak stand development and a lack of information concerning advance oak reproduct ion rnortali ty (Oliver and Larson 1990).

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Graduate Research Assistant and Professor, Dept. Forestry, Mississippi State Univ., MS; Principle Silviculturist, Southern Forest Exp. Sta., Stoneville, MS; and Associate Professor, Dept. Forestry, Mississippi State Univ., MS.

Little research has been conducted into reasons for the slow growth response of advance oak reproduction (Carve11 1967). One way to alleviate this slow growth response may be to clip oak seedlings in combination with midstory and understory competition control (Loftis 1983). Janzen and Hodges (1987) found that clipped oak seedlings, released from competing stems, had a greater growth rate than released but unclipped seedlings after three growing seasons.

Most of the research on oak regeneration conducted to date has been of an empirical nature, i.e., survival and height growth, with little emphasis on a more basic understanding of oak seedling biology. Recent interest, though, has increased in oak seedling photosynthesis (Hanson et al., 1988a, 1988b), carbon budgets (Hanson et al. , 1987), response to flooding (Pezeshki and Chambers 1985), and carbon-14 allocation patterns (Isebrands et al. , in press). These last two problem areas, slow growth response and little understanding of oak seedling biology, were the reasons why this study involving advance cherrybark oak (Quercus pagoda Raf .) reproduction was undertaken. Specifically, the objectives were to:

1. compare morphological features, gas-exchange processes, and carbon-14 allocation patterns in clipped and intact seedlings with and without release treatments; such information will aid in understanding the early growth patterns of cherrybark oak; and

2. determine if clipping cherrybark oak seedlings,combined with midstory and understory competition control, is a feasible silvicultural technique for enhancing oak reproduction.

He thods

Study Location

Three study sites, each containing advance cherrybark oak reproduction, were located on the Noxubee Wildlife Refuge, Oktibbeha and Noxubee Counties, MS. Site 1 (River Road) is located on a terrace along the Noxubee River. Stand composition is mixed pine-hardwood and the site is rarely flooded . Site 2 (Keaton Tower Road) is located within a horseshoe bend along the Noxubee River. Stand composition is mixed bottomland hardwood and the site is subjected to severe annual flooding. Site 3 (Dummy Line Road) is located within the active floodplain along Loakafoma Creek. Stand composition is also mixed bottomland hardwood with an occasional loblolly pine (Pinus taeda L.). This site is also subjected to annual flooding but only for short periods of time. Site index, base age 50 years, was from 83 for Site 1 to 98 for Site 2 (USDA 1973).

Study Design

A split-plot design with two replications per site was installed in February 1989 for Sites 1 and 2, and February 1990 for Site 3. Individual plot size was variable but was from 0.10 to 0.13 ha.

Within each plot, 40-60 cherrybark oak seedlings averaging about 40 cm in height and between 1 to approximately 15 years old, were flagged for treatment and future measurements. Treatments consisted of midstory and understory removal or no removal at the whole-plot level and seedling clipping or no clipping at the subplot level. Stem removal consisted of cutting all trees in the midstory and understory, except for cherrybark oak seedlings, with a chainsaw. Immediately after each stem was cut Tordon 101R™ (manufacturered by Dow Chemical Company, Midland, MI) was applied to the stump using a mist-spray bottle. Seedling clipping consisted of clipping approximately one-half of the cherrybark oak seedlings per plot at 2.5 cm above groundline using a hand-held shear.

Morphology Measurements

Morphology measurements were conducted monthly from May to September during- the 1989 and 1990 growing seasons. Total height and root collar diameter (one measure at groundline in 1989 and two measures perpendicular to each other at 3 cm above the groundline in 1990) were measured on each seedling. Other measurements included number of terminal flushes, length of each terminal flush, number of flushes per seedling (branch flushes included), and total number of leaves per seedling. The latter measurements were made on a subsample of seedlings during the 1989 growing season, except during September when these measurements were conducted on all seedlings. The above measurements were made monthly on all seedlings during the 1990 growing season. For purposes of this report, only measurements at the end of each growing season are included.

Gas Exchange Measurements

Leaf gas exchange and environmental measurements were conducted using an ADC™ infrared gas analyzer (manufactured by Analytical Development Company, Ltd., Herts, England). Specifically, measurements were made of net carbon-dioxide exchange rate (CER; net photosynthesis), photosynthetic photon flux density (light), stomata1 conductance, and leaf temperature. Individual leaves from five true (unclipped) seedlings and five clipped seedlings were measured in the release plot from a randomly-selected split plot on a given site. Seedlings were selected based on the following criteria: (1) seedling lag stage of development (Hanson et al., 1986); (2) equal number of terminal flushes between seedlings; and (3) undamaged median leaves along the terminal flush. Measurements were conducted hourly, until gas-exchange equilibrium was reached, for each seedling from 9 a.m. to 5 p.m. CST at various times throughout the 1990 growing season.

Carbon-14 Allocation Determinations

Carbon allocation determinations were made on cherrybark oak seedlings using ^{14}C-tracers. Determinations were made on two to five seedlings per treatment within a specific split-plot on Site 1 at four times during the 1989 and 1990 growing seasons. Seedling selection was similar to that for the gas-exchange measurements in that seedlings were at the lag stage of development and had the same number of terminal flushes at each determination.

The ^{14}C-incorporation methodology closely followed that of Isebrands and Nelson (1983) in working with cottonwood (*Populus deltoides* Bartr. ex Marsh.) seedlings. In short, 5 ml of 1 M $NaH^{14}CO_3$ was reacted with 5 ml of 20 percent lactic acid within a CO_2-impermeable mylar bag enclosed over a seedling. Seedlings were allowed to incorporate $^{14}CO_2$ for 30-60 minutes. Seedlings were harvested 48 hours later and stored at -2°C. Afterwards, each seedling was divided into various tissues, i.e., first flush leaves, first flush stem, older stem, taproot, lateral roots, etc. Each tissue was dried in an oven at 105°C for 48 hours. Subsamples taken from each tissue were then combusted using a biological oxidizer manufactured by the R.J. Harvey Instrument Co. (Hillsdale, NJ). Levels of radioactivity between tissues were calculated following liquid scintillation counting (Packard Instrument Co., Downers Grove, IL). Counts for each tissue were then expressed on a relative per gram dry weight basis (specific activity) and summed into shoot or root components to obtain average shoot and root specific activity.

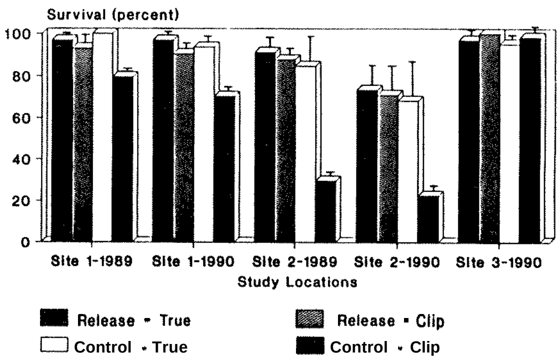

Figure 1. Cherrybark oak seedling survival as influenced by clipping and release treatments (lines represent one SE of the mean).

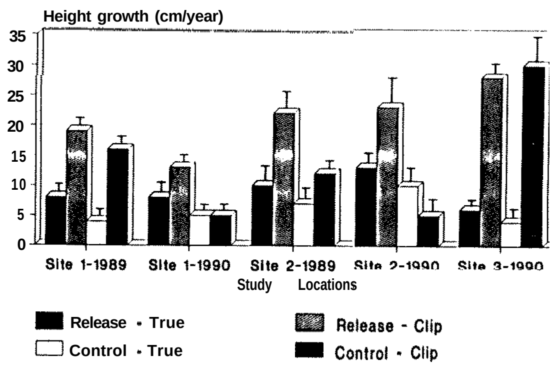

Figure 2. Cherrybark oak seedling height growth as influenced by clipping and release treatments (lines represent one SE of the mean).

Results And Discussion

Morphology

True seedlings had a higher survival percentage than clipped seedlings (Fig. 1). The lower survival of the clipped seedlings was due to poor sprouting after clipping treatments. In addition, the extremely low seedling survival on Site 2, especially non- released clipped seedlings, was due to the heavy flooding in the Spring of 1989 which silted many of the stools (seedlings stumps).

After' two growing seasons released-true seedlings had more height growth than control-true seedlings while released-clipped seedlings had more height growth than control-clipped seedlings (Fig. 2). Furthermore, clipped seedlings, regardless of midstory and understory treatment, had more height growth than true seedlings after one growing season. After the second growing season, height growth of released seedlings, regardless of clipping treatment, was greater than that of corresponding control seedlings. Similar findings have been noted for bottomland oak species including water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and cherrybark oak (Janzen and Hodges 1987).

Another way to represent seedling height growth is relative height growth (RHG) in which height growth is expressed as a percentage of pre-treatment seedling height. Of particular interest is the 100-percent line. True seedlings that reach this point have doubled their pretreatment seedling height. By comparison, clipped seedlings that reach the 100-percent line have matched their pretreatment seedling height. As expected, released-clipped seedlings had a greater RHG as compared to true seedlings (Fig. 3). Of particular interest is the RHG of the released-clipped seedlings for Site 2 after two growing seasons. These seedlings have already grown over 150 percent of their pretreatment seedling height.

Clipped seedlings also had greater root-collar diameter growth than true seedlings at the end of each growing season (Fig. 4). However, the apparent reductions in growth from 1989 to 1990 for each treatment on Sites 1 and 2 were more a reflection of the way measurements were conducted than actual growth reductions (see Methods).

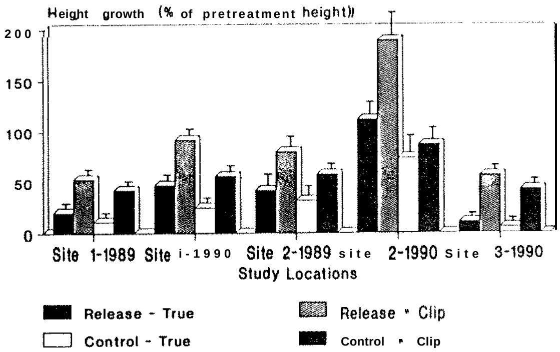

Figure 3. Cherrybark oak seedling relative height growth as influenced by clipping and release treatments (lines represent one SE of the mean.

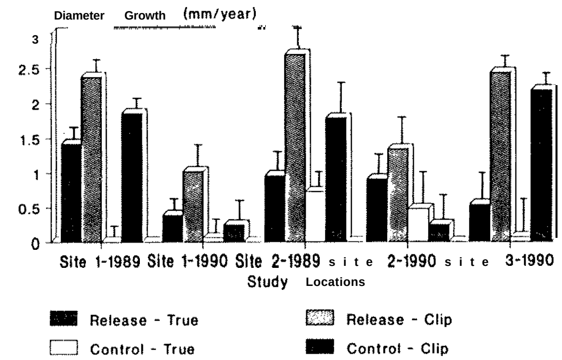

Figure 4. Cherrybark oak seedling root-collar diameter growth as influenced by clipping and release treatments (lines represent one SE of the mean).

Released seedlings had a consistently greater number of terminal flushes than control seedlings (Fig. 5). Furthermore, released-clipped seedlings had the greatest number of terminal flushes. Clipped seedlings also had a longer terminal first flush (Fig. 6) and a greater number of terminal first flush leaves (Fig. 7) as compared with true seedlings after the 1989 growing season. At the end of the 1990 growing season, released seedlings, regardless of clipping treatments, had a longer terminal first flush and more terminal first flush leaves than control seedlings. The delay in response to release among the true seedlings is probably due to the recurrent flushing habit of oak seedlings in which preformed stem units (leaf primordia and internodes) of the first flush exist in the previous growing season terminal bud (Dickson, in press). Therefore, seedling growth and development during the first growing season following release is still influenced by the conditions from the previous growing season.

Gas Exchange

Figure 8 depicts the net CER measurements for true and clipped seedlings during a typical early summer day in a release plot. While the CER of true seedlings was greater in the morning hours and that of clipped seedlings was greater during the afternoon, no consistent differences between treatments could be detected. Similar results were obtained on other days of leaf gas-exchange measurements (data not shown). Past reports have indicated that clipped northern red oak (*Q. rubra* L.) seedlings, following overstory and midstory removal, had higher rates of net photosynthesis as compared with unclipped seedlings (Kruger and Reich 1989). The lack of a consistent difference in diurnal net CER between treatments in this study was probably the result of the high degree of variability in the light levels during a given measurement time. These light patterns, as shown in Figure 9, reflect the uneven nature of the overstory canopy and thus the distribution of sunflecks.

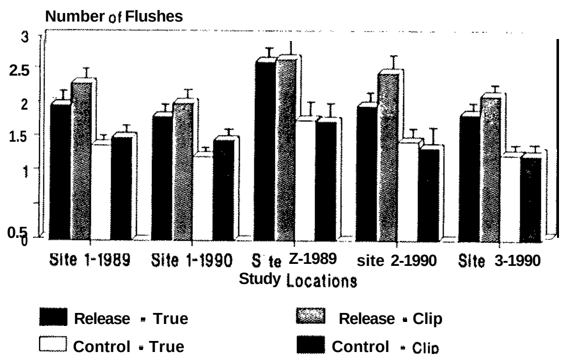

Figure 5. Total number of terminal flushes in cberrybark oak seedlings as influenced by clipping and release treatments (lines represent one SE of the mean).

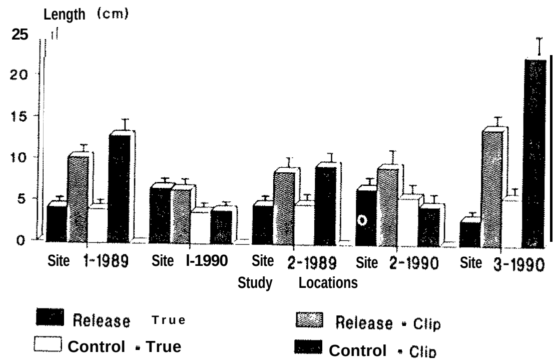

Figure 6. Terminal first flush length in cherrybark oak seedlings as influenced by clipping and release treatments (lines represent one SE of the mean).

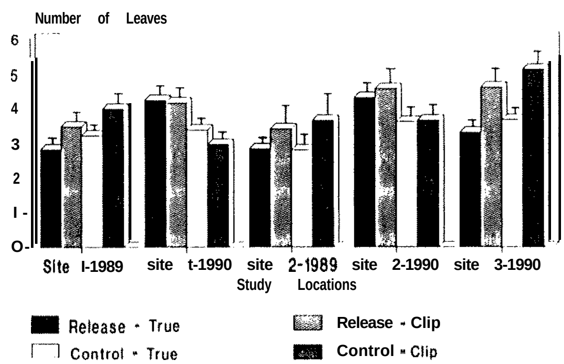

Figure 7. Number of terminal first flush leaves in cherrybark oak seedlings as influenced by clipping and release treatments (lines represent one SE of the mean).

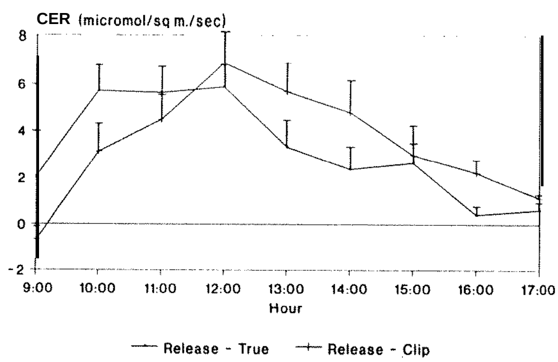

Figure 8. Net carbon-dioxide exchange rate of cherrybark oak seedlings from Site 3, Plot 4, on 11 July 1990 (lines represent one SE of the mean).

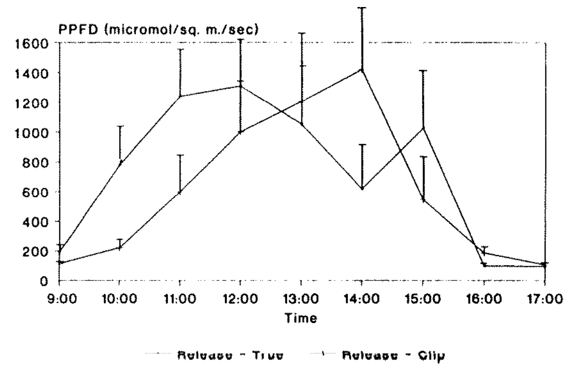

Figure 9. Photosynthetic photon flux density reaching cherrybark oak seedlings at Site 3, Plot 4, on 11 July 1990 (lines represent one SE of the mean).

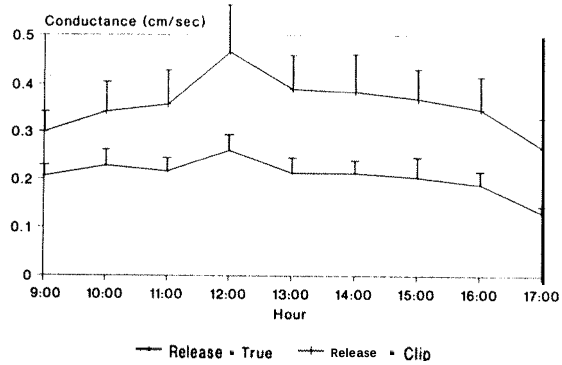

Figure 10. **Stomatal** conductance rate of cherrybark oak seedlings from Site 3, Plot 4 on on 11 July 1990 (lines represent one SE of the **mean).**

A surprising finding was the consistently greater rate of stomatal conductance of clipped seedlings over that of true seedlings throughout the day (Fig. 10). This pattern was evident in four out of the five days that gas exchange measurements were conducted in 1990. Kruger and Reich (1989) also noted increased stomatal conductance in clipped northern red oak seedlings. The greater stomatal conductance in clipped seedlings may be the result of either the stomata being more open (Blake and Tschaplinski 1986), the leaves having a higher stomatal density, or a combination of the two (Kramer and Kozlowski 1979).

Leaf temperature of clipped seedlings sometimes appeared to be slightly lower than for true seedlings (Fig. 11), but the difference may be explained by differences in radiation levels reaching the leaves.

Carbon Allocation Determinations

Average specific activity of shoots of clipped seedlings, regardless of midstory and understory treatment, was consistently greater than that for true seedlings during the 1989 growing season (Fig. 12). This was an expected finding and substantiates previous work showing greater growth allocation to shoots of coppice seedlings (Cobb et al., 1985). An unexpected finding, though, was the small difference in average shoot specific activity between true and clipped seedlings in June, 1990, and the lack of a difference in September, 1990. Unclipped seedlings may show a delayed response to release up to 3 years (Janzen and Hodges 1987). In the ^{14}C-allocation experiment, the true seedlings selected for treatment responded to release during the second growing season as reflected in their increased 14C allocation to the shoots. A possible explanation for this relatively quick response could be related to seedling origin. Advance oak reproduction may die-back and resprout several times, thereby building a larger root system (Merz and Boyce 1956). The true seedlings in this experiment were possibly seedling sprouts and could, depending on the number of die-back/resprout events and time since last resprouting, be expected to

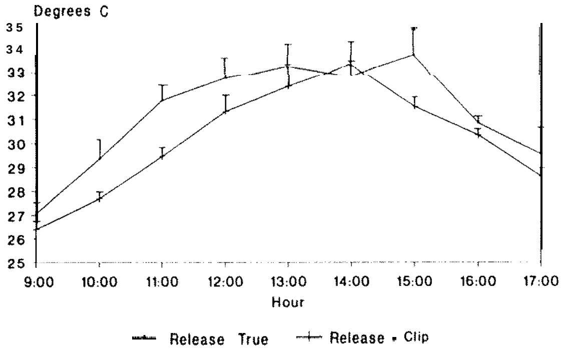

Figure 11. Leaf temperature values for cherrybark oak seedlings from Site 3, Plot 4, on 11 July 1990 (lines represent one SE of the mean).

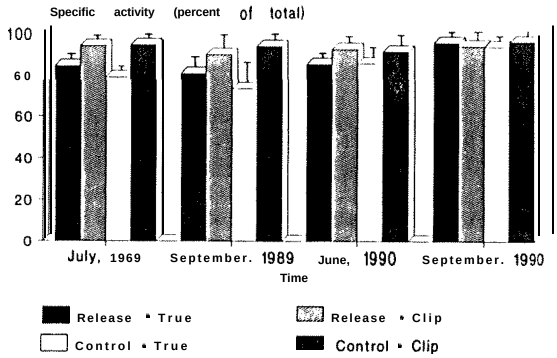

Figure 12. Average shoot specific activity of cherrybark oak seedlings from Site 1, Plots 3 and 4 (lines represent one SE of the mean).

respond quickly to release. Therefore, the small difference in average shoot specific activity during the 1990 growing season between true and clipped seedlings was likely due to increased vigor among the true seedlings.

The average root specific activity, 100 minus average shoot specific activity, of true seedlings was greater than that of clipped seedling during the 1989 growing season (Fig. 13). As with average shoot specific activity, the difference in average root specific activity between true and clipped seedlings decreased during June 1990, and did not exist in September 1990. Again, this represented possible increased vigor in the true seedlings selected for carbon allocation determinations.

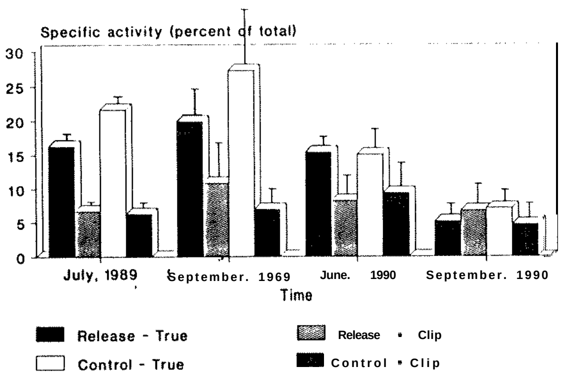

Figure 13. Average root specific activity of cherrybark oak seedlings from Site 1, Plots 3 and 4 (lines represent one SE of the mean).

Conclusions

Based on the findings to date, three conclusions can be drawn. First, cherrybark oak seedlings that were released and clipped had the highest growth rates of all the treatments. Based on the findings of Janzen and Hodges (1987) this increased growth response can probably be expected to continue for at least the next two growing seasons. Second, no distinct differences in diurnal patterns of net CER existed between released true and released clipped advance cherrybark oak seedlings. But the potential for increased gas exchange, and possible greater net CER, exists for clipped seedlings due to their greater stomata1 conductance. Work will continue in this area to determine if clipped cherrybark oak seedlings have greater photosynthetic efficiency over true seedlings by comparing light response curves. Third, differences in photosynthate allocation existed through the middle of the 1990 growing season between true and clipped cherrybark oak seedlings. This difference lessened towards the end of the 1990 growing season reflecting possible increased vigor among the true seedlings.

Based on 2-year results , clipping cherrybark oak seedlings, in combination with midstory and understory competition control, does enhance the growth and development of advance cherrybark oak reproduction. The clipping treatment mimics the dieback/resprout phenomenon of oak seedlings. Resprouting, combined with the release treatment, produces a vigorously growing oak seedling that is better able to compete for growing space. Increased seedling vigor also increases the probability of producing an oak tree of sawtimber size, especially that of cherrybark oak which is considered by some to be the best red oak (Putnam et al., 1960).

Acknowledgment

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EFFECTS OF ENHANCED ULTRAVIOLET-B RADIATION ON WATER OAK AND LOBLOLLY PINE SEEDLINGS [1]

Charles E. Rowell, Kenneth W. Farrish and Fred F. Jewel1 [2]

Abstract. Comparisons were made among greenhouse grown, water oak (Quercus nigra L.) seedlings exposed and unexposed to unfiltered UV-B light and among nursery bed grown loblolly pine (Pinus taeda L.) seedlings exposed to treatments of ambient, 25, and 50 percent over ambient, respectively. Radiated water oak seedlings had statistically less biomass development (root and shoot) and smaller heights, diameters, mesophyll cell widths, and leaf thicknesses. No physical differences were found among loblolly pine treatments; however, needles of treatments with W-B supplements contained significantly higher levels of chlorophyll B and lower chlorophyll A/B ratios.

Introduction

There is considerable evidence of stratospheric ozone depletion resulting from atmospheric pollutants, especially chloroflourocarbons (Bowman 1988). Decreased total ozone in the atmosphere may result in increased solar ultraviolet (UV)-B (280 to 320 nm) radiation reaching the earth, which may have serious environmental ramifications for animals and plants (Perry 1986). In plants, W-B radiation has been shown to inhibit photosynthesis and damage plant organelles. Of the 200 species of plants tested, approximately two-thirds were adversely affected by UV radiation (Teramura 1986). Unfortunately, most of this work has been conducted in growth chambers and greenhouses where back ground W-A (320 to 400 run) and short wavelength visible light levels are usually much lower than occur outdoors. Light at these wavelengths has been shown to play a role in photorepair systems, where damage caused by W-B radiation is reversed (Beggs et al., 1985). Consequently, plants exposed to UV-B radiation treatments in growth chambers and greenhouses may suffer abnormally high damage, resulting in over-estimation of the impact of UV-B on plants.

Only a few field studies, with normal background levels of W-A and visible light, have been conducted to evaluate the impact of increased W-B on plants (Teramura and Murali 1986). Also lacking are studies examining the effects of increased UV-B intensity on natural ecosystems, including forest ecosystems (Perry 1986). Nobel (1974) suggested that UV alteration of plant physiological processes may indirectly affect plant succession, evolution and association in the unmanaged biosphere. Southern forest ecosystems in the United States may be at the

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highest risk of damage within the nation because of higher inherent W-B radiation at these latitudes (Scotto et al., 1981). In addition, Sullivan and Teramura (1988) found that loblolly pine (Pinus taeda L.), a very important southern forest tree species, suffered large growth reductions when exposed to elevated W-B radiation in a greenhouse study. Sullivan and Teramura (1990) also reported that loblolly pine grown outdoors in pots suffered reduced growth.

Specific objectives for this study were to: (1) evaluate the effects of W-B radiation on greenhouse grown water oak (Quercus nigra L.) seedlings; and (2) evaluate the effects of supplemental W-B radiation on nursery bed-grown loblolly pine.

Methods

Preliminary Study (Greenhouse)

Two Styrofoam, 80-space, seedling containers were planted with water oak acorns-in a 1:1 peat/vermiculite mixture. After germination, seedlings were allowed to grow for 2 months in a glass-paned greenhouse. Each seedling was then numbered and measured for height (cm) and root collar diameter (mm). One container was placed under a Spectroline™ Model XX-150 medium wavelength (302 nm) ultraviolet light (W-B). The second container, also in the same greenhouse but not radiated, was used as a control. Treated and untreated oak seedlings were grown for 3 months with radiated seedlings receiving a constant dose equal to ambient outdoor W-B plus 10 percent from 1O:OO a.m. to 4:00 p.m. each day.

At project termination, three seedlings from each treatment were randomly selected for microscopic analysis of leaf tissue (Jewell et al., 1962; Jewell 1988). The remaining trees were destructively sampled and height, root collar diameter, and root/shoot ratio measured. Cholorophyll extractions from leaf samples were made using an 80 percent acetone solution (Knudson et al., 1977) and absorbency was measured using a Beckman™ Model DU spectrophotometer. Data were analyzed using a Student's t-test.

Nursery Bed Study

A nursery bed (30 x 1.5 m) located on the Louisiana Tech campus was used for this part of the study. Each bed was fumigated, fertilized, and then divided into nine treatment plots of equal size (1.5 x 1.5 m). All plots were planted February 1990 with bare-root loblolly pine 1-O seedlings on a 20 x 20 cm spacing (49 trees/plot).

Three levels of W-B intensity were administered as the treatments: (1) a control with normal background solar W-B radiation (measured monthly on-site); (2) a supplemented W-B radiation treatment simulating a supplemented W-B treatment simulating 12 percent loss of the ozone layer (25 percent increase in W-B); and (3) a supplemented W-B treatment simulating 25 percent loss of the ozone layer (50 percent increase in W-B) (Perry 1986). The three W-B treatments were combined in a randomized design replicated three times.

The supplemental W-B radiation was derived from two Q-PANEL WB 313 lamps suspended in a conventional 122-cm fluorescent light housing above the treatment plots. The method was similar to those used by Mirecki and Teramura (1984). Cellulose acetate filters were used to adjust the spectral emission of these lamps to simulate that of W-B from sunlight (Newton et al., 1979). A Spectroline™ DM-300X W-B radiometer was used to measure both background and supplemental irradiance. Lamp heights were adjusted to give the correct dose of W-B. A clock timer was used to turn the lamps on at 2 hours before and off at 2 hours after solar zenith each day. Buffer strips were used to protect adjoining plots from stray W-B radiation (Teramura and Murali 1986). Beds were fertilized (224 kg/ha 13-13-13 NPK) prior to planting to eliminate nutrient deficiencies. Artificial watering was supplied to the trees to avoid moisture stress masking of W-B damage described by Murali and Teramura (1986).

Quantitative and qualitative observations were made of tree growth and development after 2 months of growth. Tree heights and diameters (root collar) were measured. In addition, three sample trees were harvested and needle samples measured for chlorophyll concentration (A, B, and total) using an 80 percent acetone extraction (Knudson et al., 1977) and a Beckman Model DU spectrophotometer. Leaf and stem tissue from the sample trees were dried (70°C) and weighed for biomass and percent moisture determinations. Data from these measurements was analyzed using Analysis of Variance statistical techniques.

Results

Greenhouse Study

Greenhouse grown water oak seedlings were affected by enhanced W-B radiation (Table 1). Seedlings exposed to supplemental W-B light had shoot and root biomass growth reduced by 33 and 19 percent, respectively. Seedling height and diameter growth were also reduced by 24 and 22 percent, respectively. Mean chlorophyll concentration was lower in the W-B treatment trees, but the difference was not statistically significant.

Microscopic analysis of leaf tissue indicated statistical ($P > 0.05$) differences between treatments for mesophyll cell length and leaf thickness (Table 2). Mesophyll cells were smaller and leaf width was less in treated plants. Color differences were noted between similarly stained, treated and untreated water oak leaves, implying a need for further chemical analysis at the cellular level of investigation.

Nursery Bed Study

No significant differences were found among the three treatments for biomass and percent moisture content of the loblolly pine needles and aboveground stems (Table 3). In addition, no differences were found in the amounts of cholorophyll A among treatments. However, higher levels of cholorophyll B were noted in treatments of supplemental W-B, with the 25 percent enhancement being significantly different. The ratio of chlorophyll A to Chlorophyll B was significantly different among treatments, with both supplemental W-B treatments producing higher values.

Table 1. **Mean** value by seedling component of water oak seedlings exposed to enhanced **UV-B** radiation and a control.

Parameter	Treatment: Control	Treatment: Enhanced W-B	P-value of difference[1]
Shoot biomass (mg)	474	315	0.00
Root biomass (mg)	846	686	0.02
Root-shoot ratio	0.64	0.53	0.02
Seedling height (cm)	10.2	7.7	0.00
Seedling root collar diameter (mm)	2.3	1.8	0.00
Leaf width (cm)	1.5	1.6	0.07
Leaf length (cm)	5.1	5.1	0.93
Chlorophyll index [2]	75.6	55.8	0.11

[1] From t-test.

[2] The chlorophyll index is the absorbency reading at 680 nm of extracted chlorophyll divided by the sample leaf green weight (g).

Table 2. Mesophyll cell length (MCL) and leaf thickness (LT) of **UV-B** treated and untreated water oak seedling leaves growth in greenhouse conditions.

	(n)[1]	MCL	(n)	LT
		(micron)		(micron)
Control	120	34.7	30	161.3
W-B treatment	120	32.1	30	152.8

[1] Number of cells measured in the three tree samples (n).

Conclusions

Some W-B radiation effects were noted in both greenhouse-grown water oak and nursery bed-grown loblolly pine seedlings. However, treatment effects or the lack of effects may have been influenced by unforeseen or uncontrolled variations in the growth environment, specifically, light quality in the green house study and soil nutrient and moisture levels in the nursery bed study.

Table 3. Biomass and percent moisture by component, and chlorophyll A and B in needles of loblolly pine seedlings grown 3 months in seedbeds and exposed to differing levels of ultraviolet B radiation.

Variable	(n)	Control	W-B treatments: 25 percent over ambient	W-B treatments: 50 percent over ambient
Diameter (mm)	9	6.5a [1]	6.7a	6.7a
Height (cm)	9	40.3a	39.8a	39.6a
Needle DW[2]	9	1.8a	1.4a	2.1a
Needle PM[3]	9	63.1a	63.8a	62.5a
Stem DW	9	1.0a	0.8a	1.3a
Stem PM	9	68.4a	70.4a	66.1a
Total DW	9	2.8a	2.2a	3.4a
Chlorophyll A	9	1791.8a	1873. la	1790.5a
Chlorophyll B	9	1090. lb	1573.0a	1353.4ab
Ratio A/B	9	1.7a	1.2b	1.4b

[1] Values in a row followed by the same letter do not differ significantly at the 0.05 level.

[2] DW = dry weight in grams.

[3] PM = percent moisture (dry weight basis).

Results in the water oak study could have been influenced by the spectrum changes in light after passing through the glass panes of the greenhouse environment. A glass pane with a thickness of only 3.05 mm can reduce the incoming W-B to zero and the level of UV-A by as much as 80 percent (Brennan and Fedor 1987). W-A and the shorter wavelengths of visible light play a role in activating the photo repair systems of plants. Consequently, W-B related changes in growth for the water oak study may be attributed to damage caused by W-B that was not being repaired as it would in a “real world” growth environment.

The lack of differences in loblolly pine seedling growth after 2 months in a nursery bed experiment with an enhanced W-B environment could also be attributed to a lack of natural growing conditions. Fertilization and irrigation having been maintained at near optimums for plant growth may have prevented W-B effects by allowing seedlings to overcome or repair induced radiation damage.

In both studies, significant differences existed possibly implicating W-B radiation effects. However, areas of concern do exist because “real world” environmental conditions, such as changes in light, moisture and nutrients, and their interactions with plant growth during the time frame of these experiments were not factored out. Consequently, an apparent need exists for additional investigations into the effects of enhanced W-B radiation on forest species over a wide range of interactive site stress treatments, preferably in a natural growing environment.

Acknowledgments

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WATER RELATIONS OF LOBLOLLY PINE SEEDLINGS PLANTED UNDER A SHELTERWOOD AND IN A CLEARCUT [1]

Craig T. Dalton and Michael G. Messina [2]

Abstract. The influence of shelterwood conditions on loblolly pine (Pinus taeda L.) seedling water relations on two harsh east Texas sites was investigated. Site I was harvested to four overstory densities (0, 10, 20, and 40 ft^2ac^{-1}) with trenched and non-trenched subplots planted with drought-hardy seedlings. Predawn and mid-day total xylem water potentials and seedling growth were measured in the subplots. Site II was harvested to two overstory densities (0 and 30 $ft^2\ ac^{-1}$) and planted with loblolly pine seedlings. Seedlings were sampled for total xylem water potentials beginning during predawn hours and continuing at intervals throughout the day. Stomata1 conductance measurements were taken on the same seedlings at the same intervals with a whole-seedling porometer. On Site I, overstory basal area positively influenced seedling water potentials. Growth was not significantly affected by overstory treatment and trenching did not substantially affect seedlings. On Site II, water potentials and stomata1 conductances were highest during the morning hours and lowest in the afternoon. The presence of an overstory increased water potentials but did not significantly affect stomata1 conductance.

Introduction

The native range of loblolly pine (Pinus taeda L.) extends from Delaware eastern Texas, where it is limited by available soil moisture (Dorman 1976; van Buijtenen et al., 1976). In some areas of east Texas, the clearcut-and-plant regeneration methodology has repeatedly led to plantation failure due to high soil temperatures and low soil moisture levels. One regeneration technique which presumably ameliorates the severe conditions of a clearcut on these harsh sites is the shelterwood method.

The shelterwood method involves removing the present forest stand through two or more partial cuts which eventually expose the regeneration to full light conditions. The overstory offers shelter to seedlings by decreasing soil surface temperatures and early season water loss (Childs and Flint 1987). The amount of overstory left to shade the site can be varied depending on the species and landowner objectives. Shelterwood methodology is not well developed for loblolly pine in east Texas.

Both the shelterwood and clearcut regeneration techniques alter the ground level microclimate. In order to determine the specific effects of these regeneration systems on seedling performance, the physiology of seedlings planted in each system was compared. Water stress can be particularly important to newly-planted seedlings since root systems may be underdeveloped at establishment (Brix 1979). One way of

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determining plant water stress is by measuring the free energy status of water within the plant (Scholander et al., 1965), which is an assessment of water potential. Stomata1 conductance is also important for controlling water loss and photosynthesis (Slayter 1967, Murphy and Ferrell 1982). The main objective of this study was to determine the effects of a loblolly pine overstory on underplanted seedling total xylem water potential, stomatal conductance, survival, and growth.

Site Description

Two research sites (I and II) were established in Cherokee County, Texas, (31° 41'N, 95° 15'W). Sites deemed difficult to regenerate were selected with the guidance of industry foresters. Both sites have an average elevation of 321 ft above mean sea level. Average annual precipitation is around 45 inches distributed fairly evenly throughout the year. The initial stand composition for Sites I and II was a loblolly-shortleaf pine (P. echinata Mill.) type with an understory composed of mixed hardwoods. The sites were harvested to varying overstory densities with dominant loblolly pines being the favored residual species. Both sites were broadcast burned prior to harvest. After harvesting, all unwanted pines and hardwoods were injected with picloram.

Site I

Four overstory treatments consisting of 0, 10, 20, and 40 ft^2/ac of residual basal area were replicated five times in plots measuring 390 x 390-ft (3.5 ac). Two replications of each of the four overstory treatments had trenched and non-trenched subplots established near the center of the main treatment plot. The 0, 20, and 40 ft^2 overstory treatments were chosen for water relations study.

The trenched 15 x 15-ft subplots were established to determine the competitive effects of the overstory trees on the water relations of the seedlings. Subplots were trenched to a depth of 4 ft, lined with polyethylene , and backfilled. The roots of the overstory trees were thus severed and unable to reenter the subplot through the polyethylene liner. Non-trenched subplots were established near the trenched subplots, but at a sufficient distance to avoid trenching influences. The non-trenched subplots enabled monitoring of the water relations of seedlings under competition for water and nutrients from the overstory.

The subplots were planted with 25 1/0 drought-hardy loblolly pine seedlings from the Texas Forest Service Indian Mound Nursery in Alto, Texas. The seedlings were planted in January 1990 at a 2.5 x 2.5-f t spacing. The spacing was close to minimize plot size and trenching. The seedlings were treated with an ammonium soap-base deer repellent ("Hinder," Leffingwell, Inc., Brea, California) soon after planting. Weeds were controlled with a directed-spray application of a l-percent glyphosate solution to any unwanted vegetation as needed to keep the subplots uniform and isolate the effects of the overstory.

Site II

Site II was located 1 mile SE of Site I. The plots on Site II were 500 x 500-ft (5.7 ac) and consisted of two overstory treatments (clearcut at 0 and shelterwood at 30 ft^2/ac of residual basal area). There were five replications of each overstory treatment planted in January 1990 at a 6 x 8-ft spacing with l/O loblolly pine seedlings obtained from a Temple-Inland, Inc., nursery.

Materials And Methods

The field season for all measurements was from April 15 to October 3, 1990. This time frame was chosen because the greatest water stress in the study area occurs in the summer months when rainfall is minimal and vapor pressure deficits are high.

Water Potential Measurements

Water potential measurements were conducted on both Sites I and II using a pressure chamber apparatus (PMS Instruments Co., Corvallis, Oregon) according to techniques developed by Scholander et al. (1965). On Site I, predawn measurements were made approximately every 2 weeks (11 sessions) on a single fascicle from seedlings in the trenched and non-trenched subplots under the 0, 20, and 40 ft^2 residual basal area overstory treatments. Predawn leaf water potentials are useful in estimating the value of soil water potential actually experienced by the plant (Whitehead and Jarvis 1981). Measurements were taken on one randomly selected seedling in each trenched/ non-trenched subplot in each overstory treatment plot. The same seedlings were sampled throughout the field season unless they expired or became deficient in suitable fascicles in which case new seedlings were sampled for the remainder of the study.

In order to determine the lowest water potentials attained by the seedlings under each treatment of Site I, midday measurements were taken on 9 out of 11 predawn measurement days. To minimize variable environmental effects, all midday measurements were limited to clear days and begun at 1 hour past solar noon when air temperatures were normally highest (Valigura and Messina 1991).

On Site II total xylem water potential measurements were taken approximately every 2 weeks (12 sessions). Water potential measurements began during the predawn hours and continued at 3-hour intervals until about 1800 hours. Six seedlings were sampled for water potentials from a shelterwood plot and an adjacent 500-ac clearcut.

Stomata1 Conductance Measurements

Stomata1 conductance measurements were taken on nine selected days during the field season with a CS-102 whole-seedling porometer (Micromet Systems, Inc., Vancouver, B.C., Canada). Conductance measurements were taken concurrently with water potential measurements on the same six seedlings per basal area treatment. Stomata1 conductance measurements began around 900 hours and continued at the same 3-hour interval as water potential measurements, ending around 1800 hours. Stomata1 conductance measurements usually could not be taken earlier due to dew formation on the seedlings.

The CS-102 whole-seedling porometer requires an estimate of seedling leaf area to calculate stomata1 conductance. Therefore, the same seedlings could not be sampled throughout the field season due to the destructive sampling technique employed for leaf area determinations. At the end of the sampling day, seedlings used for stomata1 conductance measurements were clipped at groundline and transported to a laboratory facility for leaf area determinations. Leaf area was measured through a water displacement technique described by Johnson (1984).

Growth and Survival

All seedlings in the trenched and non-trenched subplots were measured for root collar diameter, height, and survival soon after planting, and then monthly during the field season.

Results And Discussion

Site I

Seasonal average total xylem water potentials on Site I were significantly ($P < 0.05$) affected by the amount of overstory present both at the predawn and midday sampling period (Fig. 1, Table 1). Duncan's new multiple range test showed that on a seasonal basis , seedling predawn and midday water potentials increased significantly with overstory density. The less stressful conditions offered by the overstory on certain harsh sites in east Texas are evident both at the predawn and midday sampling period throughout the season. Theoretically, any decrease in plant water potential below -0.2 or -0.3 MPa should inhibit growth (Kramer and Kozlowski 1960). Water stress in loblolly pine does not occur until predawn values fall below -0.5 MPa, while moderate stress occurs at values below -0.8 MPa, and severe stress occurs below -1.4 MPa (Seiler and Johnson 1988). Predawn water potentials averaged higher than those at midday for all sampling sessions and treatments throughout the season.

The removal of overstory root competition from the seedling subplots did not significantly ($P < 0.05$) raise the predawn or midday water potential values in the 0 and 20 overstory densities (Fig. 1). A trenching effect could be expected in the plots with an overstory, but not in the clearcut plots. Seedlings in the trenched subplots under the 20 ft^2 overstory did not have significantly higher seasonal average water potentials than those in non-trenched subplots at either the predawn or midday sampling periods. Even though later inspection revealed some overstory roots present in the trenched plots (primarily in the 40 ft^2 treatment), our seasonal analysis indicated a significant trenching effect under the 40 ft^2 overstory for both the predawn and midday periods. Seedlings in the trenched subplots under the 40 ft^2 overstory had higher seasonal average water potentials than did seedlings in non-trenched plots. On a seasonal basis, the higher water potentials in the trenched plots indicated a negative effect of the assumed denser root systems under the 40 ft^2 overstory. However, seedling water potentials at both the predawn and midday period in the non-trenched subplots under the 40 ft^2 overstory averaged higher or

Table 1. Basal. area effects on underplanted loblolly pine seedling seasonal average total. xylem water potentials for Site I. Data for trenched and non-trenched subplots combined.

Basal Area	Mean Xylem Water Potential	
	Predawn[1]	Midday[2]
(ft^2 acre-‘)	(MPa)	(MPa)
0	-0.502 a[3]	-1.071 a
20	-0.435 b	-0.824 b
40	-0.368 c	-0.685 c

[1] Means of 88 seedlings measured on 11 days in each basal area.

[2] Means of 72 seedlings measured on 9 days in each basal area.

[3] For each column, means followed by the same letter are not significantly different at the P = 0.05 level.

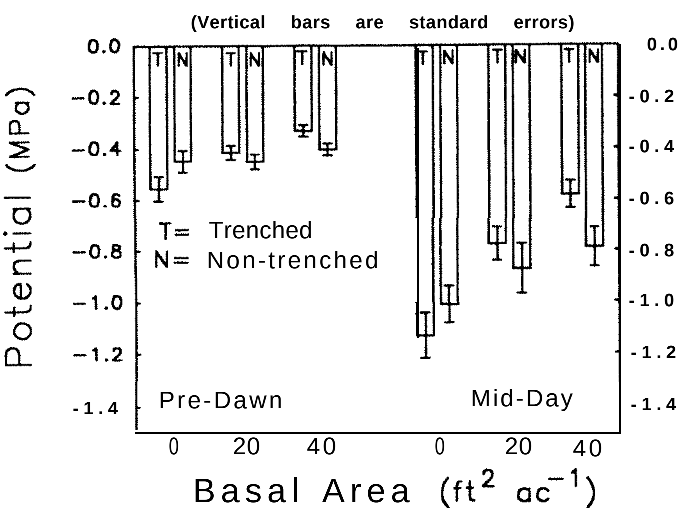

Figure 1. Seasonal average total xylem water potentials for loblolly pine as affected by trenching, basal area, and time of day (Site I).

equal to values obtained in any other treatment presumably due to the less stressful environment. High rainfall during our sampling season (over 20 in. of rainfall from the beginning of May to the end of September) likely decreased trenching influences.

A seasonal trend in water potentials was not observed. Both predawn and midday water potentials appeared to be controlled by the length of time to the last substantial rainfall. Since ‘this period was often short, the water potentials were usually relatively high for most treatments.

Water potentials on Site I increased with overstory density (Fig. 1). Survival behaved similarly. On Site I, overstory presence significantly

(P < 0.05) increased survival (Fig. 2). When the data for trenched/non-trenched subplots are combined by overstory, the highest survival was obtained under the 40 ft^2 basal area, with 95.5 percent of the seedlings remaining at the end of our sampling season. Survival decreased to 91.5 and 88.5 percent in the 20 ft^2 and 10 ft^2 basal areas, respectively. The survival differences among the 10, 20 and 40 ft^2 treatments were not significant (P < 0.05), but the clearcut plots did have significantly (P < 0.05) lower survival rates than all other treatments, with only 51 percent of the seedlings alive at the end of the season. Most mortality occurred during the months of July and August. Trenching did not have a significant effect on survival under-any overstory.

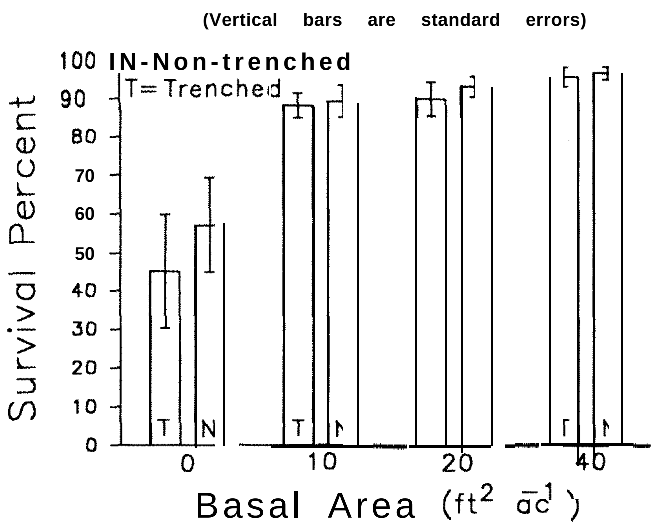

Figure 2. Loblolly pine growing season survival as affected by basal area and trenching (Site I).

Averages of height and RCD growth at the end of the season indicate a trend of increasing growth with basal area up to 20 ft^2 (Fig. 3). At 40 ft^2, shade seemed to limit growth. However, basal area effect on growth was not significant (P < 0.05).

Seedlings in trenched subplots under an overstory had slightly greater seasonal average height and RCD growth than those in adjacent non-trenched subplots (Fig. 3). However, the differences between the trenched and non-trenched subplots over all treatments were not significant (P < 0.05). In the clearcut plots seasonal growth between trenched and non-trenched subplots was approximately equal.

Site II

Seasonal average diurnal water potentials for both clearcut and shelterwood treatments were highest during the predawn periods and decreased throughout the day on every sampling session (Fig. 4). Seasonal average water potentials in the shelterwood were significantly (P < 0.01) higher diurnally than in the clearcut, thus indicating a less stressful environment in.the shelterwood. Once again, there was no seasonal trend in water potentials likely due to the above average amount of rainfall. The water potential values measured on Site II were probably influenced more by time since the last rainfall rather than time of year.

Stomata1 conductance values for both clearcut and shelterwood treatments decreased throughout the day on every sampling session. Seasonal

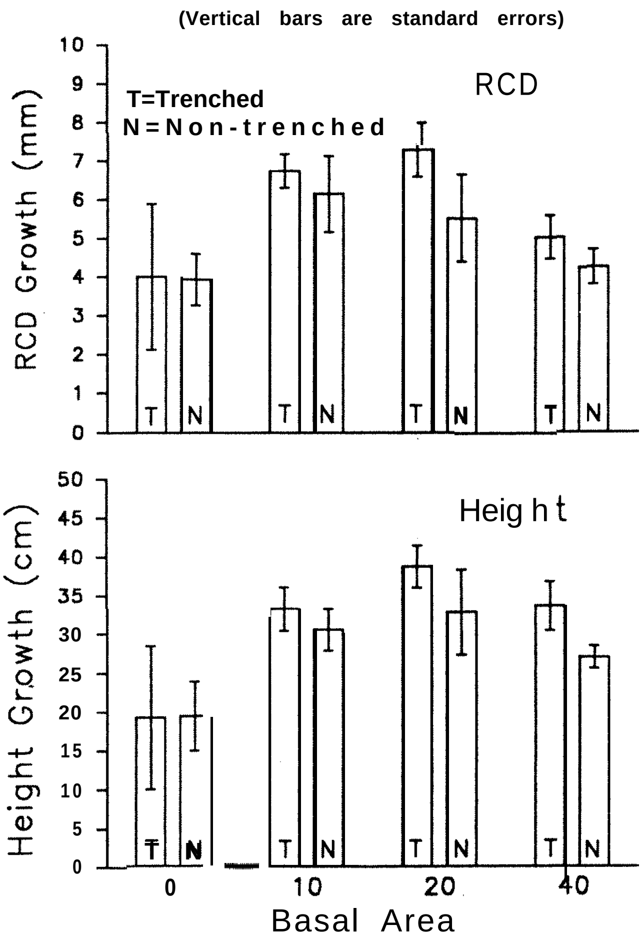

Figure 3. **Loblolly** pine seedling height and root collar diameter as affected by basal area and trenching **(Site** I).

average stomatal conductance values in the clearcut and shelterwood for the later hours of the day were not significantly (P < 0.05) different (Fig. 5). However, at the earliest sampling hour seasonal average conductance values were significantly (P < 0.05) higher in the shelterwood. This early morning difference was not present during all sampling sessions. On an individual day basis the shelterwood had higher daily average conductance values during the August 3 and September 21 sampling sessions, while on the May 16 and July 9 sampling sessions the clearcut had higher average conductance values. For all other sampling sessions there were no discernable differences between the clearcut and shelterwood. The cause of these differences is unknown. Vapor pressure deficits, irradiance, and soil moisture levels in a clearcut have been shown to be different from those in a shelterwood (Childs and Flint 1987, Holbo and Childs 1987, Valigura and Messina 1991). Since these variables directly affect stomatal conductance (Jarvis 1980; Johnson and Ferrell 1983; Teskey et al., 1986), more precise interpretations of overstory effects can be made when comparisons using these microclimate factors are performed.

Conclusions

The overstories on Site I significantly influenced both water potentials and survival rates in the trenched and non-trenched subplots. Predawn and midday water potentials increased with overstory basal area. Survival was also highest in the heaviest shelterwood and lowest in the clearcut seemingly due to the water stress levels associated with the seedlings. Even though the measurement season was fairly wet, there were periods of low soil moisture and high daytime temperatures which appeared to have the greatest water stress effect on the clearcut seedlings.

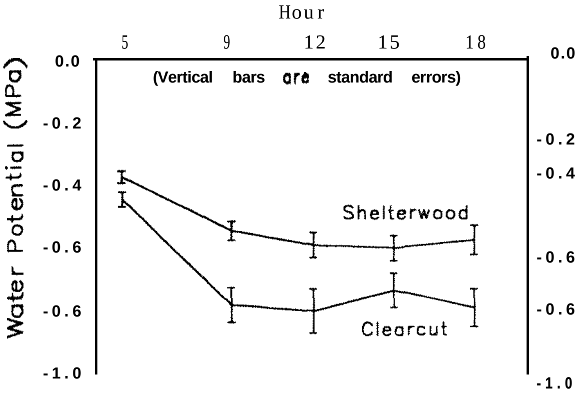

Figure 4. Seasonal average loblolly pine water potentials in clearcut and shelterwood treatments (Site II).

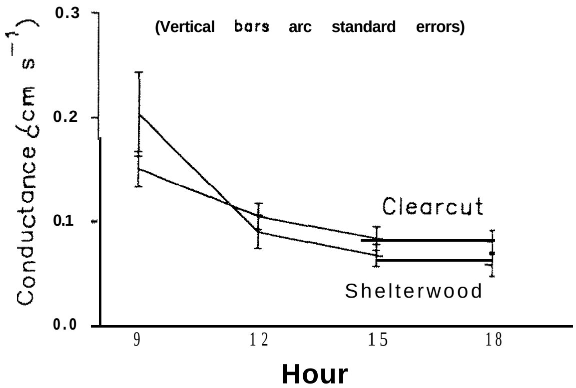

Figure 5. Seasonal average loblolly pine stomatal conductance in clear-cut and shelterwood treatments (Site II).

The seedling water potential values on Site II were the same as those in Site I, with the seedlings under an overstory having higher values than those in a clearcut. Overstory influences on seedling stomata1 conductance are difficult to express at this time due to the variability and insignificant differences between treatments.

Although growth on Site I averaged highest under the 20 ft^2 overstory and least in the clearcut, the overstory effect was not significant ($P < 0.05$). Trenching had little or no effect on seedling water potential, survival, or growth on Site I. Therefore, overstory root water competition was assumed to be minimal.

Generally, the seedling environment was made less severe with increasing overstory density, demonstrated by the higher water potentials of understory seedlings on both Sites I and II, and the greater survival where an overstory was present on Site I. Although not significant ($P < 0.05$), any amount of overstory increased growth above that in clearcut plots. Highest average growth occurred under the 10 ft^2 and 20 ft^2 basal areas, while the 40 ft^2 was intermediate, and the clearcut lowest, albeit not significantly ($P < 0.05$). Research conducted by McDonald (1976) on the regeneration of five western conifers provided similar results where the overstory aided establishment, but reduced growth rates. The optimum overstory density for seedling survival and growth on these harsh east Texas sites seems to range from 20 to 30 ft^2 of residual basal area per acre.

Acknowledgments

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PHYSIOLOGICAL DIFFERENCES IN SUN AND SHADE FOLIAGE INTHINNEDANDUNTHINNED LOBLOLLYPINE [1]

Jaroslaw Nowak, John R. Seiler, Ben H. Cazell, and Richard E. Kreh [2]

Abstract. This study investigated, in detail, the physiology of sun and shade needles of lo-year-old loblolly pine (Pinus taeda L.) 3 years after thinning. Physiological rates were measured in the crowns of trees under natural light conditions. During the third growing season, light conditions in thinned stands did not differ between the upper and lower third of the crown. However, light levels in the lower third of unthinned stands were almost three times less than the upper third. Gas exchange rates did not differ between the crown positions in thinned stands, but were significantly reduced in lower crowns of unthinned stands. Observed physiological differences were not related to needle water potential or chlorophyll content, but to differences in light levels.

Introduction

Foresters recognized as early as the nineteenth century that thinning stands allowed the remaining trees to grow at higher rates. Since that time, many different thinning systems have been developed. The basic idea is however the same--to provide the residual trees with more space, so they have larger shares of light, nutrients, and water, resources which often are limiting factors to tree growth. Allocation of these resources to the remaining trees increases their quality and dimensions. This allows desirable products to be obtained in a shorter time span.

Although the growth advantages of thinning are well documented, the physiological mechanism responsible for the acceleration of growth is not well understood. Commonly faster growth is attributed to the increased photosynthetic capacity of remaining trees due to larger crown dimensions and live crown ratios, as well as to the increased photosynthesis of the lower parts of the crowns. It is not clear, however, how the foliage in thinned and unthinned stands differ physiologically, and if these differences have any biological significance. Some authors have suggested that the increased growth is related to better water supply to the remaining trees (Lilieholm and Hu 1984, Bassman 1988).

Ginn (1989), in her master's thesis, tried to answer many of these questions by examining physiological and growth differences in 8-year-old stands of loblolly pine (Pinus taeda L.) for 2 consecutive years after thinning. Ginn (1989)

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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was investigating the physiological potential of needles by taking measurements in full sun light. This study is a continuation of this research and a further attempt toward understanding the physiological mechanism of tree response to thinning of the stand. In our investigations, we examined physiological rates in the crowns of the trees under natural light conditions.

The specific objectives were to asses gas exchange parameters and water status of loblolly pine canopies during the third growing season following thinning. Chlorophyll content of needles and light conditions in the stands were examined as well.

Materials And Methods

The Study Site

The study is conducted in three replicate loblolly pine stands 0.222-ha each planted- in 1980 at the Reynolds Homestead Agricultural Station, located in Critz, Virginia. The stands were planted at an original spacing of 3.05 by 3.05 m on an old-field site. A Lloyd clay loam soil supports stand 1, and a Wickham loam soil supports stands 2 and 3. Estimated site indices in these stands range from 23 to 25 m (loblolly pine, base age 25). The original stand characteristics at age 8 have been reported by Ginn (1989).

On March 2, 1988, one-half of each stand was chosen randomly and thinned mechanically by removing alternate diagonal rows, so that square spacing was maintained. The remaining trees averaged in residual basal area of 9.4 m^2/ha in thinned plots and 16.8 m^2/ha in the control plots. A two-row buffer of trees was maintained along borders of stands and between plots. In May and September of 1988, glyphosate herbicide was applied to both treatments to control understory vegetation, primarily Rubus spp., Lonicera spp., and Rhus spp.

Two years after thinning (following the trees' tenth growing season), average heights for thinned and unthinned stands were basically the same, 10.4 and 10.7 m, respectively. Average diameter at breast height was larger in thinned stands, 19.2 versus 17.4 cm for unthinned stands. Live crown diameter and live crown ratio were again larger for thinned stands, 4.84 m and 69.2 percent versus 3.88 m and 62.9 percent for unthinned stands (Ginn 1989).

Physiological Measurements

Gas exchange measurements were made at one month intervals, beginning on May 24 through September 28, 1990. Needle photosynthesis, transpiration, needle conductance, and respiration were measured using the Li-Cor™ 6200 portable photosynthesis system (Li-Cor, Inc. Lincoln, Nebraska).

The measurements were taken on subsamples of needles within the crowns of six permanent, scaffolded trees (one tree per each treatment/block combination). Two subsamples of needles were measured in the upper and lower third of each crown, resulting in a total of 24 samples on each measurement day. The average of the two subsamples was taken as the experimental unit. Two fascicles of needles were inserted into the cuvette of the Li-Cor 6200 for measurement of photosynthesis, without detaching needles from the twig.

The cuvette was held in position to maintain a natural leaf angle and actual light conditions. After photosynthesis, respiration was measured by detaching needles from the twig and covering the cuvette with aluminum foil. Both photosynthesis and respiration were monitored as a change in CO, over 30 seconds inside a quarter-liter cuvette.

After completion of gas exchange measurements, needles were transported in plastic bags to the laboratory for surface area measurements. This was accomplished by measuring fascicle diameters and lengths on that portion of needles which were enclosed in the Li-Cor cuvette. Dry weight of the needles was then determined following drying at 65°C to constant weight.

Water potentials were also measured on cut twigs coming from the upper and lower third of the crowns of three subsampled trees per treatment combination, starting in May and continuing through October 1990. A pressure chamber (PMS Instrument Corp., Corvallis, Oregon) was employed.

Chlorophyll content of the needles was analyzed on a sample of needles collected on September 21, 1990. Samples were collected from the upper and lower crown position on the same trees which gas exchange was measured. Chlorophyll content was analyzed with a spectrophotometer following extraction with N,N-Dimethyl-formamide.

Results

In general the most visible effect of thinning is light availability to the lower canopy of thinned stands. This was also true in the case of our study. During the third growing season after thinning, differences in light levels between the upper and lower crown positions of thinned stands were not significantly different. The upper crowns however, had slightly higher light levels. In unthinned stands the lower third of the crowns were receiving almost three times less light ($p = 0.02$) as the upper third (Table 1).

Table 1. Light levels, chlorophyll contents and water potentials in thinned and unthinned loblolly pine stands at two crown positions during the third growing season after thinning.[1]

Treatment	Crown position	Light		Chlorophyll content		Water potential	
		($\mu E/m^2 sec$)		(mg/gf wt)		(MPa)	
Thinned	upper	588	n.s.	1.127	n.s.	-1.34	(0.08)
	lower	465		1.088		-1.19	
Unthinned	upper	591	(0.02)	1.161	n.s.	-1.39	(0.07)
	lower	203		1.136		-1.25	

[1] Numbers in parenthesis are probability levels for statistical significance between the upper and lower crown positions.

Net photosynthesis expressed on a leaf area basis reflected the differences in light availability (Table 2). In thinned stands, the differences between upper and lower crowns were not significantly different, with the upper being slightly higher. However, upper crowns in unthinned stands had photosynthetic rates over two times higher than lower crowns (p = 0.01).

Table 2. Gas exchange parameters in thinned and unthinned loblolly pine stands at two crown positions during the third growing season following thinning.[1]

Treatment	Crown position	Net photosynthesis (Ps)		Respiration (Rs)		Ps/Rs	
		----- (μMol CO_2/m^2 sec) -----					
Thinned	upper	2.79	n.s.	0.597	n.s.	5.02	n.s
	lower	2.34		0.523		5.21	
Unthinned	upper	2.92	(0.01)	0.541	(0.05)	7.19	(0.07)
	lower	1.40		0.441		4.24	

[1] Numbers in parenthesis are probability levels for statistical significance between the upper and lower crown positions.

The same pattern of differences was observed for respiration (Table 2), needle conductance, and transpiration (Table 3), all expressed on a leaf area basis. In thinned stands, the differences between upper and lower crowns were slight and not statistically significant. In unthinned stands, upper crown values were much higher and statistically significant at p = 0.05 for respiration and transpiration , and p = 0.01 for conductance.

In all cases--with the exception of respiration--upper crowns in unthinned stands showed higher physiological activity in comparison with both parts of the crowns in thinned stands. For unthinned stands, photosynthesis to respiration (Ps/Rs) ratios were over 69 percent higher in upper crowns than in lower crowns. This ratio for upper crowns in unthinned stands is also about 40 percent higher than the Ps/Rs ratios for both crown positions in thinned stands (Table 3).

The chlorophyll content of needles was the same regardless of crown position or treatment (Table 1). The upper crown needles contained more chlorophyll than the lower crowns, but the differences were not significant.

Table 3. Stomatal conductance and transpiration in thinned and unthinned loblolly pine stands at two crown positions during the third growing season following thinning.[1]

Treatment	Crown position	Needle conductance	Transpiration
		(mMol/m² sec)	(mMol/m² sec)
Thinned	upper	59 n.s.	1.59 n.s.
	lower	53	1.51
Unthinned	upper	69 (0.01)	1.78 (0.05)
	lower	52	1.34

[1] Numbers in parenthesis are probability levels for statistical significance between the upper and lower crown positions.

Water potential results showed the same pattern in thinned and unthinned stands, with upper crowns having more negative values (Table 1). In addition, the average water potentials for the treatments (thinned and unthinned stands) were not significantly different.

Discussion

In the previous research in these stands, needles were exposed to full sun light during gas exchange measurements. It was found that the needles in the lower crowns of thinned plots had photosynthetic rates, needle conductances, and water potentials similar to the sun grown needles in the upper crowns of both thinned and unthinned plots (Ginn et al., 1988; Ginn 1989). Our results obtained under stand light conditions support these previous findings, showing no significant differences in physiological activity of needles from the upper and lower crowns of thinned stands.

There is lack of research showing physiological differences between upper and lower crowns in thinned versus unthinned stands. However, researchers agree that the physiology of sun and shade shoots can differ significantly because of adaptations to different light conditions (Kull and Koppel 1987).

Shade foliage is often reported to have higher chlorophyll content (Aleksejev 1975, Koch 1976: cited in Kull and Koppel 1987). Schaffer and Gaye (1989) reported that the chlorophyll content of mango (Mangifera indica L.) leaves increased as percent of shading increased from full sun light to 75 percent. Higginbotham (1974), however, working with mature loblolly pine found no difference between the chlorophyll concentrations in needles from different crown positions. Higginbotham's results are in agreement with our results.

In our study, the differences in photosynthesis between sun and shade needles can not be explained by differences in water potentials or chlorophyll content. Likewise, Schaffer and Gaye (1989) found that with mango leaves the response to light regime did not depend on leaf chlorophyll or nitrogen concentrations.

It seems likely that needle photosynthetic characteristics and resources use efficiency, can acclimate to the light regimes under which they expand and mature. But they can also be modified to new light conditions, even after full maturation, as was shown by Syvertsen (1984) for citrus (Citrus paradisi Macf. and C. sinensis L.) leaves. The latter may happen i-recently thinned stands with lower crown foliage suddenly exposed to increased light level.

In our study, during the third growing season following thinning, all the needles experienced sun or shade conditions while emerging. Thus, the different characteristics of gas exchange parameters in upper and lower crowns was likely due to the light availability. Cregg et al. (1990) found higher needle conductance in loblolly pine the first year after thinning. As in our results, they concluded that it was differences in light interception and crown exposure that was responsible for the observed changes.

Some investigators suggested that the most important factor contributing to the increased growth of the remaining trees in thinned stands is better water supply. Donner and Running (1986) found that with increasing stand density, lodgepole pine (P. contorta var. latifolia Engelm.) had more negative predawn leaf water potentials. Lower water potentials corresponded with higher seasonal soil moisture depletion. Reduction of overall transpiring leaf surface area, reduction of live root density, and reduction of canopy interception of precipitation were concluded as factors improving the water relations of thinned stands.

Similar results were reported by Lilieholm and Hu (1984). In their study, the most intensively thinned stands, had significantly more water in the upper 2.4 m of the soil profile than control stands. Loblolly pine diameter growth was also the greatest on the most intensively thinned plots.

Cregg et al. (1990) also found soil water potential to increase significantly in response to thinning of loblolly pine. In our study, although soil water potentials were not monitored, the observed physiological differences could not be attributed to differences in plant water relations. Xylem water potentials between treatments did not differ and midday xylem water potentials did not decrease below -1.4 MPa, suggesting water was plentiful for both treatments. This is similar to Cregg et al. (1990) who found no differences in loblolly pine xylem water potentials in response to thinning in 48 out of 55 sampling periods, despite changes in soil water potential.

The physiological activity of upper crowns in unthinned stands was even higher than that of upper crowns of thinned stands. We speculate, that needles in the upper crowns of unthinned stands are trying to compensate for the lower production in the shaded needles. Photosynthetic compensation due to changes in source or sink strength has been reported for several species (Kramer and Kozlowski, 1979). In the case of thinned stands the physiological activity was evenly distributed within the crowns. It seems that thinning may affect gas exchange rates of the whole crown, since we observed that the upper crowns "slow down" while the lower crowns "speed up" due to increased light availability.

This conclusion is further supported by the photosynthesis to respiration ratio, which is an indicator of the efficacy of the tree assimilation-respiratory apparatus. The highest efficiency was observed for the upper crowns of the unthinned stands, lower and almost even for the both crown positions in the thinned stands, and the lowest in the lower crowns of the unthinned stands (Table 2).

Baker and McKiernan (1988) concluded that many higher plants can modify their photosynthetic apparatus not only in response to changes in light intensity, but also to changes in spectral composition. These changes may involve variation in gene expression and message translation which are interceded by blue light receptors and phytochrome. In this way plants can optimize their photosynthetic rates depending on light conditions. It is important that in the natural environment, mature leaves are capable of changing their physiology from "sun" to "shade" (or the other way around), over relatively short time (Baker and McKiernan 1988).

Thinning probably induces this kind of changes in the lower crown foliage, increasing its gas exchange activities. It is possible that the physiology of the upper crown foliage is affected also. The mechanism which allows the plant to adapt to changes in light conditions and an understanding of its physiological importance is still poorly understood (Baker and McKiernan 1988).

Conclusions

During the third growing season following thinning, the light conditions in the lower crowns of thinned stands were similar to those in the upper crowns. This had an effect on gas exchange rates, which were similar in the upper and lower crowns of thinned stands. In unthinned stands due to light differences, those rates were significantly reduced in the lower crowns. Thinning may affect physiology of the whole crown, increasing gas exchange rates in the lower crowns but decreasing them in the upper crowns. The upper crowns of unthinned stands remain the most efficient part of photosynthetic-respiratory apparatus. Observed changes parallel differences in light levels, but appear to have no relationship to water potential or chlorophyll content.

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RADIATION AND THERMAL ENVIRONMENT IN AN EAST TEXAS CLEARCUT AND SHELTERWOOD [1]

Richard A. Valigura and Michael G. Messina [2]

Abstract. Approximately 202,000 ha of pine forestland in east Texas have been deemed difficult to regenerate by forest industry and governmental agencies. Traditional clearcut-and-plant regeneration methodology for loblolly (*Pinus taeda* L.) pine has sometimes led to failure of plantationsinthisegion. One possible solution is the shelterwood system of harvesting. The object of this study was to compare the radiation and thermal regimes of a shelterwood with those of a clearcut in east Texas. Two adjacent, 1.4-ha plots were chosen for the current research. One plot was clearcut, the other plot was harvested such that 9.18 $m^2\ ha^{-1}$ of pine basal area remained to form the shelter-wood overstory. Sampling was performed from midwinter (February 10) until late summer (September 11) of 1989. One measurement each of net radiation and photosynthetically-active radiation (PAR) was obtained at a point location in the center of each treatment area 1.52 m aboveground. Air temperature was measured at 0.3 m above the soil surface to approximate seedling height. The daily total amounts of net radiation and PAR received were greater in the clearcut than in the shelterwood. Loblolly pine performs best at high light levels; therefore, lower light levels in the shelterwood may result in lower seedling production rates. Daily mean near-ground air temperatures in the shelterwood were lower or equal to those in the clearcut. The data indicate that the microenvironment created beneath the shelterwood canopy was less thermally stressful for seedlings.

Introduction

Approximately 202,000 ha of pine forestland in east Texas have been deemed difficult to regenerate using traditional clearcut-and-plant regeneration methodology. High growing season soil surface temperatures, low levels of soil moisture, and intense irradiation stress young seedlings and cause high mortality. Acceptable regeneration levels could be fostered by providing these sites relief from high temperatures and direct irradiance. Messina (unpubl. data) found that artificial shade furnished by commercial tree shades afforded a 25 percent survival advantage (after 2 years) for loblolly (*Pinus taeda* L.) pines planted on deep, sandy soil in northeast Texas. Other studies have documented the value of artificial shade for early survival on harsh sites for a variety of species. Many are listed in a recent review on heat damage in tree seedlings (Helgerson, in press).

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Although the use of artificial shade will likely ameliorate the heat load on young seedlings on many east Texas sites, it is prohibitively expensive in the South. One possible substitute for artificial shade consists of a partial forest canopy left after an incomplete harvest (i.e., a shelterwood cut). The canopy should alleviate the severe conditions often afforded by clearcuts in east Texas. Shelterwood understory environments are usually less harsh than clearcut environments because much of the total site net radiation is dissipated in the overstory canopy (Holbo and Childs 1987, McCaughey and Saxton 1988).

Shelterwood methodology is not well developed in east Texas. However, there is a strong interest among forest products companies in cultivating this technology as a substitute for current clearcutting practices in order to improve regeneration success on the most difficult sites. This study compared a shelterwood's radiation and thermal environments to that of a clearcut in east Texas by quantifying net radiation, photosynthetically-active radiation (PAR), and air temperatures. The objective was to use these measurements to describe the environment to which a loblolly pine seedling would be exposed if planted in both shelterwood and clearcut conditions.

Study Site

The study site was located in Cherokee County, Texas, at 31° 41'N, and 95° 15' W with an average elevation of 98 m above mean sea level. Average slope of the site was 3° with an aspect of 152°. The climate is warm-temperate, humid, and continental, influenced by the humid winds from the Gulf of Mexico. Precipitation is distributed fairly equally throughout the year, with a mean of 114.3 cm. The site index is 24.4 and 22.9 m (base age 50 years) for loblolly and shortleaf pine, respectively (Coffee 1975). The stand was naturally regenerated, approximately 50 years old, and had a mean basal area of 13.1 $m^2\ ha^{-1}$ in pine sawtimber (20.3 cm dbh or greater) before harvesting.

Materials And Methods

Two plots measuring 36.23 m^2 (1.42 ha) were chosen for this study. One plot was clearcut and the other was harvested, such that 3.72 m^2 of pine basal area remained to form the shelterwood overstory. Undesired trees of all species were then injected on both plots. All environmental measurements were conducted in a centrally-located measurement plot.

Sampling for environmental data was performed from midwinter (February 1O:Julian day 41) until late summer (September 11: day 254) 1989. Recording was done on a 24-hr basis throughout the sampling period, with all instrument signals read every 10 seconds and averaged over 30-minute intervals . Due to numerous instrument and weather problems, data are discontinuous; however, a sufficient number of uninterrupted intervals existed to enable quantification of differences between the sites at certain stages throughout the sampling period. Short intervals from the sampling period were chosen to represent the site microclimate during different seasons.

These periods were: a 10-day period in winter (February 16-25: days 47-56), an 11-day period in early spring (March 19-29: days 78-88), two 3-day periods in early summer (July 3-5, days 184-186; July 10-12, days 191-193), and a 13-day period in late summer (August 30-September 11; days 242-254 minus day 249). Two more days were chosen, February 23 (day 54) and July 10 (day 191), to illustrate diurnal fluctuations in measured values.

All instruments were purchased from Campbell Scientific Inc., Logan, Utah. Instrument readings were recorded by model CR10 battery-powered dataloggers and connected AM32 multiplexers.

One measurement each of net radiation and photosynthetically-active radiation (PAR: 0.4 - 0.7 µm wavelength) was taken at a point location in the center of each treatment plot with a Q4 net radiometer (Radiation Energy Balance Sys terns) and a LI-190SZ quantum sensor (LI-COR) , respectively. Both instruments were mounted horizontally at 1.2 m above the soil surface to avoid excessive interference of the surface radiation regime by the instrument and its supporting structures while still giving a reasonable approximation of the radiation environment of seedlings (Holbo and Childs 1987). Air temperature was measured at 25.4 cm above the soil surface with a Campbell Scientific Model 207 Humidity Probe, containing a Fenwall Electronics UUTS1J1 Thermistor. This level was chosen to approximate seedling height.

Results And Discussion

Radiation

Net radiation is the fundamental quantity of energy available on the site to be partitioned among evaporation, air and soil heating, and other processes such as photosynthesis. Large positive values indicate that a greater amount of energy is available for these processes.

Photosynthetically-active radiation, the visible fraction of solar radiation, is the energy available for seedling production. The unit used to express PAR is the mole (a mole of quanta, or the energy in a photon, the fundamental particle of radiation). About one-third to one-half of direct solar radiation is photosynthetically active as compared with over two-thirds of diffuse radiation (Landsberg 1986, Fitter and Hay 1987). We found a highly significant ($P < 0.001$) correlation between daily totals of net radiation and PAR in both the clearcut ($r= 0.99$) and the shelterwood ($r= 0.98$) for the sampled days (Fig. 1 and 2).

Figures 1 and 2 show the variable nature of net radiation and PAR across time. The peaks in both are associated with clear days while the troughs are indicative of cloudy days. In both stand treatments, net radiation and PAR increased from winter through spring to late summer signifying that more energy was supplied to the sites as the growing season progressed. This can be explained by the variation of incoming shortwave radiation with season, due to the changing daylength and sun elevation. As net radiation is directly related to incoming shortwave radiation, it also varies seasonally. This also explains the higher net radiation values measured in both treatments on day 191 than on day 54, an increase of 6.36 and 2.62 MJ m^{-2} d^{-1} in the clearcut and shelterwood, respectively (Table 1).

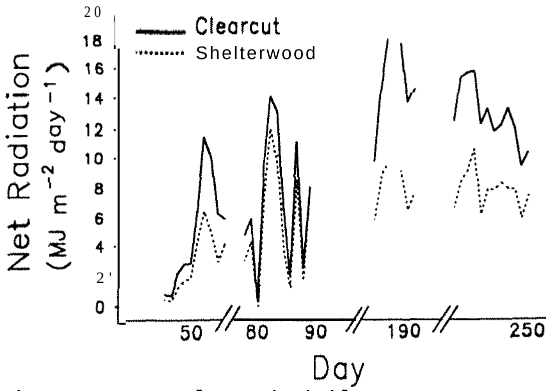

Figure 1. Selected daily net radiation totals in an east Texas clearcut and loblolly pine shelterwood.

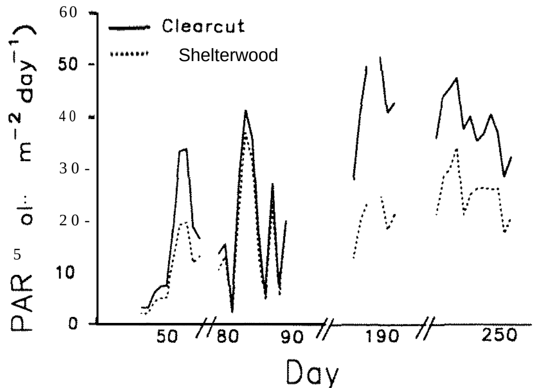

Figure 2. Selected daily photosynthetically-active radiation totals in an east Texas clearcut and loblolly pine shelterwood.

Table 1. Daily totals and means of measured thermal and radiation components in the shelterwood and elearcut treatments on both sample days.

Component	Day 54		Day 191	
	CC	SW	CC	SW
Net radiation[1] (MJ m^{-2} d^{-1})	11.39	6.4	17.75	9.02
PAR[1] (mol m^{-2} d^{-1})	3.35	1.94	5.12	2.43
Air temperature[2] (°C)	3.4	2.3	30.4	28.8

[1] Daily totals calculated through trapezoidal rule.
[2] Daily means of 30-minute averages.

Due to instrumentation complications, the data are too discontinuous to determine the maximum daily total net radiation received by each site. Therefore, the data displayed for days 242 through 254 should not be construed as maximum annual values. Nevertheless, the data show the ability of the overstory to affect the ground-level radiation regime at several intervals through the year.

Figure 3 illustrates the diurnal fluctuations in net radiation in both stand treatments for days 54 and 191. These data are useful for tracking the effects of a partial overstory on radiation budgets at near-ground level through the normal course of a day. During daylight hours (approximately 0800 hours to 1700 hours on day 54 and 0600 to 2000 hours on day 191), net radiation in both the clearcut and the shelterwood was positive; i.e., the sites were gaining more radiation than they were losing. Net radiation normally becomes positive sometime after sunrise and negative sometime before sunset on clear days. Nighttime net radiation was negative for both sites on both days although values were more negative on day 54 than on day 191.

The overstory effect also influenced the variability in net radiation received within each day. Daily totals of net radiation (see Fig. 1), and PAR (see Fig. 2), were greater in the clearcut than in the shelterwood. This is due to the interception of direct solar radiation in the shelterwood overstory canopy. Net radiation in the shelterwood was lower than that in the clearcut during most of the daylight period and either the same or greater at night, particularly on day 54 (Fig. 3). The greater nighttime net radiation in the shelterwood can be attributed to increased longwave radiation directed downward from the tree boles, and the shielding effect of the overstory on outgoing long-wave radiation. Longwave radiation emitted from the vegetation and soil components is absorbed by the canopy, which also emits radiation downward (Mahrt 1985). These tend to balance each other, keeping the balance closer to zero (Holbo et al., 1985).

Day 54 was clear and day 191 was partly cloudy. This is reflected by the relative smoothness of the net radiation curves for the clearcut. Sunfleck incidence (full sunlight conditions) can be seen in the shelterwood on both days as peaks in Figure 3, where shelterwood net radiation sometimes exceeded that in the clearcut. This demonstrates the variable nature of the seedling microenvironment beneath a shelterwood. Net radiation in the shelterwood fell to very low levels during shade incidence, even after very high values during sunflecks (Fig. 3). Holbo et al. (1985) found that shelterwoods offered some degree of control over duration of full sun and shade events which can be a major benefit of shelterwood overstories on harsh sites.

Trends in daily PAR (Fig. 4) were similar to those discussed for net radiation. Daily total PAR received was greater in the clearcut than that beneath the shelterwood overstory; values were also greater on day 191 than on day 54 for both treatments, an increase of 1.77 and 0.49 mol $m^{-2} d^{-1}$ in the clearcut and shelterwood, respectively (Table 1).

Net radiation is partitioned on the site among sensible heat, latent heat, soil heating, and photosynthesis (Penman 1948, Monteith 1973, Richards 1979). Due to its small magnitude, photosynthesis is considered negligible in terms of heat dissipated (McCaughey 1982). In dry conditions, most available radiation is used in soil heating and sensible heat transfer. This can lead to extremely high soil surface temperatures which can either damage the seedling directly or increase the air temperature around the seedling. In the absence of wind, heat load can reach dangerous levels (Jarvis 1980, Monteith 1980). Therefore, overstory alleviation of excessive irradiance loads should aid in seedling survival (Williamson 1973; Helgerson et al., 1982).

Paradoxically, loblolly pine is an early successional species and, therefore, intolerant of excessive shade. It performs best in high PAR

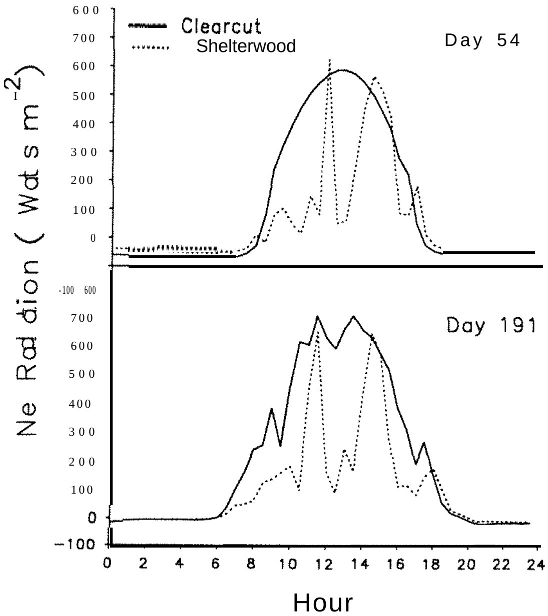

Figure 3. Diurnal net radiation for 2 selected days in an east Texas clearcut and loblolly pine shelterwood.

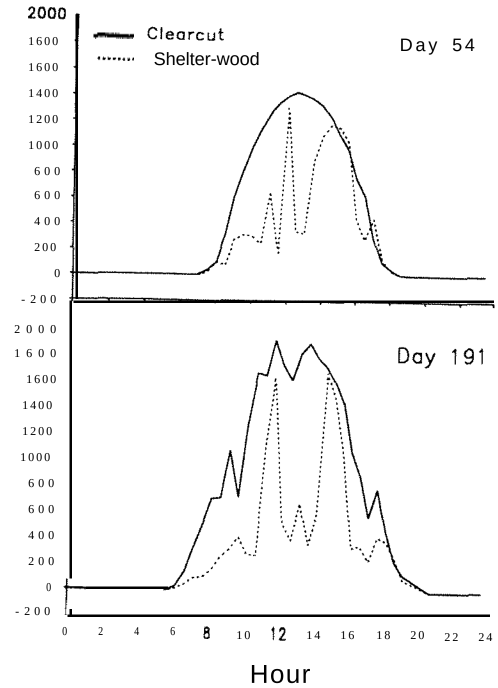

Figure 4. Diurnal photosynthetically-active radiation for 2 selected days in an east Texas clearcut and loblolly pine shelterwood.

levels because it has a high light saturation point for photosynthesis (Kramer and Decker 1944, Bormann 1956). Teskey et al. (1986) measured the effect of various levels of PAR on net photosynthesis, transpiration and stomatal conductance in 2-year-old loblolly pine seedlings. They found a light compensation point (where net photosynthesis is zero) at 25 $\mu mol\ m^{-2}\ s^{-1}$ and no evidence of light saturation at 1450 $\mu mol\ m^{-2}\ s^{-1}$, the highest rate they tested. As shown in Figure 4, the shelterwood microclimate allows full light intensities (PAR) to reach the forest floor for only very short periods. Therefore, while the overstory is present, the lower PAR levels may result in lower production with a shade-intolerant species like loblolly pine.

Air Temperature

Daily mean near-ground air temperatures in the shelterwood were lower or equal to those in-the clearcut (Pig. 5). The diurnal trends in air temperature indicated that the overstory effects on air temperature were greatest in the daylight hours and least at night (Fig. 6). The most pronounced difference between clearcut and shelterwood air temperatures occurred prior to noon (difference of 7.4°C at 0900 hours on day 54 and 6.8°C at 1130 hours on day 191). A 1- to 2-hr lag between air temperature and net radiation is fairly common (Rosenberg et al., 1983), and was apparent on both days (Fig. 3 and 6).

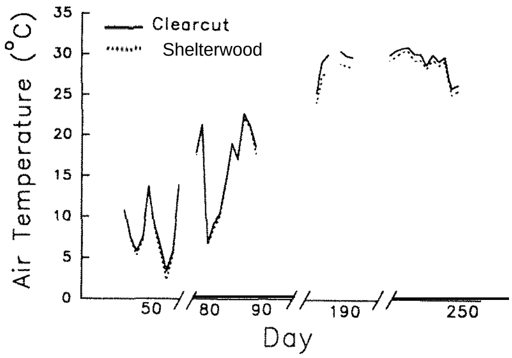

Figure 5. Selected daily temperature means in an east Texas clearcut and loblolly pine shelterwood.

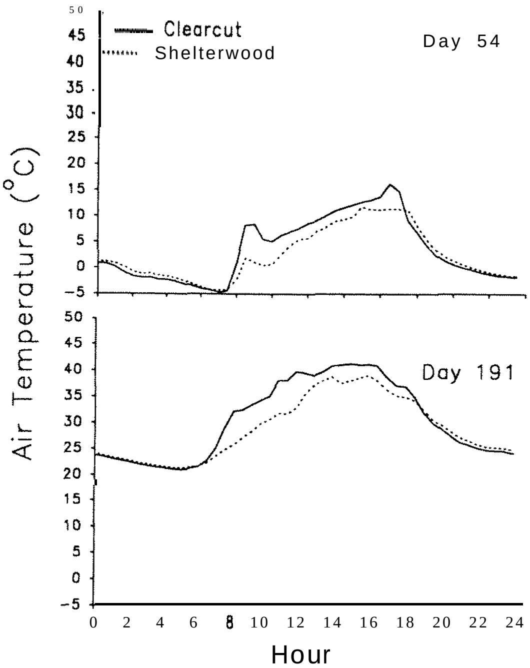

Figure 6. Diurnal air temperatures for 2 selected days in an east Texas clearcut and loblolly pine shelterwood.

Daily mean air temperatures were higher in the clearcut than those in the shelterwood on both sample days (Table 1). However, air temperatures in the shelterwood were lower during the day and higher at night than those measured in the clearcut. This is directly due to the overstory canopy shielding against incoming shortwave radiation during the day and insulating against loss of longwave radiation at night (Holbo and Childs 1987). The correlation between net radiation and air temperatures on both sites was highly significant ($P < 0.001$) but it was greater in the clearcut ($r = 0.75$, day 54 and $r = 0.91$, day 191) than in the shelterwood ($r = 0.65$, day 54; $r = 0.69$, day 191). The higher correlation in the clearcut might signify that near-ground air temperatures in the clearcut were more closely related to net radiation. The data indicate that the microenvironment created beneath the shelterwood canopy was less thermally stressful for seedlings.

Conclusions

The near-surface environment of a loblolly pine clearcut and shelterwood site in east Texas were instrumented to determine treatment effect on the radiation and thermal components of microclimate. The shelterwood treatment showed lower net and photosynthetically-active radiation loads, and lower daytime air temperatures than the clearcut. The data demonstrated the ability of the shelterwood to alter the near-surface microclimate. It is difficult to conclude what effects the altered microclimate would have on loblolly pine seedling performance due to the opposing factors of the somewhat more favorable micrometeorological factors in the shelterwood, coupled with competition for site resources between seedling and overstory trees. Further studies on seedlings established in clearcuts and shelterwoods are necessary to fully assess the effects of these treatments on seedling physiology.

Acknowledgments

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PHYSIOLOGY OF RED-COCKADED WOODPECKER CAVITY TREES: IMPLICATIONS FOR MANAGEMENT [1]

William G. Ross, David L. Kulhavy, Richard N. Conner, and Jianghua Sun [2]

Abstract. Resin flow and tree moisture stress, frequently used as indicators of pine susceptibility to pine bark beetle (Dendroctonus frontalis Zimm.) attack, were measured in loblolly (Pinus taeda L.) and shortleaf (P. echinata Mill.) pines red-cockaded woodpecker [Picoides borealis (Vieillot)] cavity trees in the Angelina and Davy Crockett National Forests in eastern Texas. No differences in moisture stress were found, whereas resin flow between different types of cavity trees and control or potential trees varied by site and species. It was concluded that effects of red-cockaded woodpecker activity on host tree susceptibility to southern pine beetle will vary by site, tree species, and host tree condition. Forest management activities and general forest health are much more important for the bird's long-term survival.

Introduction

The red-cockaded woodnecker, [Picoides borealis (Vieillot)] (RCW) has been listed as an endangered species since 1970. Endemic to the pine ecosystems of the South and Southeastern United States, the RCW is unique in that it excavates its nest cavity exclusively in living pine trees. Old-growth longleaf (Pinus palustris Mill.), loblolly (P. taeda L.), and shortleaf (P. echinata Mill.) pines are primarily utilized. RCW populations in Texas (Conner and Rudolph 1989) and southwide (Costa and Escano 1989) are generally declining due in large measure to loss of old-growth southern pine habitat (U.S. Fish and Wildlife Service 1985).

In addition to excavating its nest cavities in living pines, RCWs peck small holes, called resin wells, around the entrance to their cavities that cause a copious flow of pine resin down and around the boles of their cavity trees. The resin serves primarily as a barrier against rat snakes [Ela he obsoleta (Say)], a major RCW pre ator (Jackson 1974; Rudolph et al., 1990b), but has little effect on cavity competitors (Rudolph et al., 1990a).

The major cause of RCW nest cavity tree loss in Texas loblolly and shortleaf pine stands is attack by southern pine beetle (Dendroctonus frontalis Zimm.) (Conner et al., in press; Kulhavy et al. , in press). Trees favored by the RCW for nest cavities tend to be old, ranging from approximately 60 to 130 years

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of age in loblolly and shortleaf pine, with slow radial growth, and infection with red-heart rot (Phellinus pini) (Lennartz et al., 1983; Conner and O'Halloran 1987). These characteristics tend to place pine trees at high risk of attack by southern pine beetle and associated phloem-boring beetles, even when bark beetle populations are generally at endemic levels.

A primary host defense against bark beetles is preformed resin flow (Hodges et al., 1979; Payne 1980; Paine et al., 1985). Preformed resin is resin present in the resin ducts at the time of wounding or insect attack, rather than resin produced as a response to these stimuli. Bark beetles, particularly during endemic population levels, are frequently unable to effectively colonize and kill pines with high resin flow. An important factor in predisposing trees to successful attack by phytophagus insects is moisture stress (Kozlowski 1969). Lorio and Hodges (1977) found that stressed pines were much less able to resist southern pine beetle attack than unstressed trees.

The purpose of this investigation was to examine the effects of RCW cavity excavation and resin-well pecking on preformed resin flow and tree moisture stress. Implications for management based on these and other characteristics of RCW cavity trees are also explored.

Methods And Materials

Study Area

Data were collected in the Bannister Wildlife Management Area of the Angelina National Forest (ANF), Texas, periodically during the growing seasons of 1988 and 1989. Data were also collected in 1989 and 1990 from the Neches district in the Davy Crockett National Forest (DCNF), Texas, approximately 100 km west of the ANF. Sampling dates in the ANF were June 3, July 15, September 1, and October 21 of 1988; and May 24, July 21, August 16, and September 29 of 1989. In the DCNF sampling times were June 6, July 20, August 22, and October 14 in 1989; and March 10, June 5, July 23, and September 7 in 1990.

Red-cockaded woodpecker cavity trees evaluated in this study were either loblolly or shortleaf pines. Sample trees in the ANF were divided into four categories:

1. Trees currently used for RCW nesting and roosting that had been established prior to 1987 (old active);
2. Trees previously used for nesting and roosting, but currently not used by RCW (inactive);
3. Trees having external characteristics associated with RCW trees, such as age, evidence of heart-rot, etc., but no history of RCW utilization (potential); and
4. Cavity trees activated after 1987 (new active).

In the DCNF, only the first three categories were sampled. Approximately 60 trees, divided into appropriate categories, were sampled in each forest. The same trees were used in each sampling interval.

Resin Flow

Resin flow was measured by driving a 2.54-cm diameter circular arch punch to the interface of xylem and phloem at approximately 1.4 m (dbh) on the bole. All holes were punched between the hours 1900 and 2200 to minimize effects of diurnal variation in resin flow (Nebeker et al., 1988). Triangular metal funnels were then placed under the wounds to divert exuded oleoresin into a clear plastic graduated tube. Resin flow was recorded at 8 and 24 hr after wounding. After recording 24-hr values, funnels and tubes were removed, and the bark plug replaced. To avoid placing undue additional stress on the trees, only one sample/tree was taken during any one sampling period.

Tree Moisture Stress

Tree moisture stress was evaluated by using the pressure chamber technique (Scholander et al. , 1965)) . Twig samples were taken from the upper crowns of cavity and non-cavity trees selected from among the trees samples for resin flow. Sampling took place during peak stress periods of 1300 to 1500 hr at the same times as resin sampling. Only established active RCW trees, inactive trees, and potential trees were evaluated. Newly excavated cavity trees were too few in number to provide valid comparisons. Twigs were removed by a blast from a 12-gauge shotgun, and moisture status evaluated within 60 sec of removal.

Analysis

Data were analyzed on the Honeywell™ CP-6 mainframe computer at Step-? hen F. Austin State University using the SPSS[x] statistical software package (Norusis 1985). Resin flow at 8 and 24 hr was analyzed separately for each species and by each forest. Resin flow by species was analyzed using the Mann-Whitney U-Wilcoxon Rank Sum test (Norusis 1985). Kruskal-Wallis non-parametric rank analysis was used to evaluate resin flow by cavity tree type. When differences were significant at $P \leq 0.05$, ranked means were separated using the non-parametric multiple comparison procedure described by Daniel (1990). The same procedures were used to analyze tree moisture stress.

Results

Resin flow did not vary significantly by sample date in either forest, most likely because sampling was done only during the growing season of spring, summer, and early fall. Samples were therefore pooled for analysis into their respective species and cavity tree types for each forest, without reference to sample date.

Overall, 8- and 24-hr resin flow, combining all cavity tree types, showed significant differences in resin flow by species (Table 1), but with the species exhibiting highest resin flow differing by forest. In the ANF, shortleaf pine had higher resin flow, while loblolly pine had the highest resin flow in the DCNF.

Analysis of sample trees by cavity tree type showed similar difference by species. In the ANF there were no significant differences in resin flow

Table 1. Overall resin flow at 8 and 24 hr by species and forest.

Species	N	Angelina NF 8 hr	Angelina NF 24 hr	N	Davy Crockett NF 8 hr	Davy Crockett NF 24 hr
		--- (ml) ----			--- (ml) -----	
Loblolly	267	4.23 a[1] (3.98)[2]	6.12 a (5.97)	126	5.89 b (5.21)	9.21 b (8.66)
Shortleaf	181	5.59 b (4.82)	8.14 b (7.25)	331	3.53 a (3.89)	5.93 a (6.31)

[1] Resin flow differs significantly between species for 8- and 24-hr measurements [$\alpha = 0.05$, Mann-Whitney U-Wilcoxon Rank Sum Test (Norusis 1985)].

[2] Standard deviation.

Table 2. Eight- and twenty-four hr resin flow by cavity tree type, Angelina National Forest, 1989 and 1990.

Cavity tree type	N	Loblolly pine 8 hr	Loblolly pine 24 hr	N	Shortleaf pine 8 hr	Shortleaf pine 24 hr
		--- (ml) ----			---- (ml) -----	
Active	81	4.23 a[1] (4.15)[2]	6.12 a (6.58)	68	4.27 a[1] (3.44)	6.04 a (5.20)
Inactive	65	4.78 a (4.08)	6.20 a (5.60)	23	5.64 a (5.88)	8.03 a (8.48)
Potential	95	3.75 a (3.81)	5.59 a (5.57)	40	4.59 a (4.06)	7.09 a (6.77)
New active	29	4.57 a (3.84)	7.64 a (6.26)	29	10.07 b (4.50)	14.70 b (6.68)

[1] Within columns, means followed by the same letter are not significantly different [$\alpha = 0.05$; Kruskal-Wallis non-parametric rank analysis (Norusis 1985); non-parametric multiple comparison procedure (Daniel 1990)].

[2] Standard deviation.

by cavity tree type in loblolly pine (Table 2). In shortleaf pine, however, newly activated cavity trees had much higher resin flow than old active, inactive or potential.

Table 3. Eight- and twenty-four hr resin flow by cavity tree type, Davy Crockett National Forest, 1989 and 1990.

Cavity tree type	N	Loblolly pine 8 hr	Loblolly pine 24 hr	N	Shortleaf pine 8 hr	Shortleaf pine 24 hr
		--- (ml) ----			---- (ml) -----	
Active	22	9.27 b[1]	13.82 b[1]	82	3.70 ab	5.90 ab
		(5.38)[2]	(9.21)		(4.50)	(7.28)
Inactive	48	5.67 ab	9.21 ab	111	2.59 a	4.27 a
		(4.89)	(8.27)		(3.11)	(4.78)
Potential	56	4.75 a	7.39 a	136	4.25 b	7.39 b
		(4.97)	(8.24)		(3.85)	(6.49)

[1] Within columns, means followed by the same letter are not significantly different [α = 0.05; Kruskal-Wallis non-parametric rank analysis (Norusis 1985); non-parametric multiple comparison procedure [Daniel 1990)].

[2] Standard deviation.

Table 4. Tree moisture stress by species and cavity tree type, Angelina National Forest, 1988 and 1989.

Cavity tree type	N	Loblolly pine	N	Shortleaf pine
		---- (MPa) ----		----- (MPa) -----
Active	17	1.77	16	1.70
		(0.14)'		(0.19)
Inactive	6	1.76	11	1.78
		(0.18)		(0.14)
Potential	25	1.78	10	1.68
		(0.17)		(0.19)

[1] Standard deviation.

Results from the Davy Crockett National Forest were different (Table 3). Active loblolly pine cavity-trees had significantly higher resin flow than the potential trees. For shortleaf cavity trees, resin flow was highest in the potential trees and lowest in inactive trees.

No significant differences were found in tree moisture stress between cavity tree types in either forest (Tables 4 and 5). It should be emphasized, however, that these are results taken only during hours of peak stress and do not include newly activated cavity trees.

Table 5. Tree moisture stress by species and cavity tree type, Davy Crockett National Forest, 1989 and 1990.

Cavity tree type		Loblolly pine		Shortleaf pine
		---- (MPa) ----		---- (MPa) ----
Active	10	1.77 (0.15)[1]	16	1.82 (0.15)
Inactive	8	1.69 (0.30)	11	1.78 (0.10)
Potential	18	1.73 (0.22)	10	1.74 (0.17)

[1] Standard deviation.

Discussion

Resin-well pecking by RCWs on active cavity trees is a continual wounding of the tree, resulting in a sustained flow of resin at the wound site. Results indicate that this pecking activity can affect preformed resin flow in some cases, but the direction and magnitude of the effects are interactive with tree species and site factors. Effects may also be transient.

In the ANF only newly excavated shortleaf pine cavity trees had resin flow significantly different (in this case higher) than other cavity and potential tree types. That the older active trees were at the same levels as inactive and potential trees indicates the effect is temporary. The loblolly sample trees in the ANF, with no differences in resin flow between any of the cavity-tree types, are apparently unaffected in this respect by RCW cavity excavation and resin-well pecking.

Results from the DCNF indicate that loblolly cavity trees may respond to woodpecker activity by increased resin flow, with the opposite being the case for shortleaf pine. These results, however, may be complicated by site differences. In the ANF, both shortleaf and loblolly pine cavity trees occurred in all colonies, though loblolly predominated. In the DCNF, where annual rainfall tends to be lower, loblolly pine was more restricted to bottomland and moist areas, while trees on ridges tended to be relatively pure stands of shortleaf. Blanche et al. (1985) found that bottomland pines responded to wounding by increased resin flow, while trees on ridges did not.

Essentially uniform tree moisture stress data, regardless of cavity-tree type or species indicates that RCW activity is not having an effect on moisture stress during the peak stress hours. This does not necessarily mean that it is the same at all hours of the day for all sites. Diurnal measurements, beginning during the predawn period and ending in early evening, would give more complete results, but are highly problematic due to the size of the trees, potential impact on the crown from repeated sampling with a shotgun, and the presence of the birds in close proximity to the cavity trees early and late in the day.

It is difficult to generalize about the effect of RCW activity on the relative susceptibility of its host to bark beetle attack. The effect, if any, is variable by site and species (and also probably by initial host condition). Its importance is probably minor compared with effects of forest management activities on the site, such as prescribed burning, thinning, and midstory removal. RCW cavity trees, particularly loblolly and shortleaf, are naturally at a stage in life where vulnerability to mortality from pine bark beetles is high.

Long-term, proactive management strategies to favor the RCW in the loblolly/shortleaf forests of Texas should be aimed at reducing risk of bark beetle attack by increasing overall forest health. Increasing tree species diversity, increasing age class diversity, and favoring native species are a few general suggestions frequently made for reducing bark beetle risk (Hicks et al., 1979). Management guidelines should be flexible enough to allow for site specificity in optimizing general forest health in a particular region.

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DYNAMICS OF ADVANCE REGENERATION IN FOUR SOUTH CAROLINA BOTTOMLAND HARDWOOD FORESTS [1]

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Abstract. Between 1987 and 1989, germination and survival of 10,419 tree seedlings growing in the understories of four oak-gum bottomland hardwood forests in South Carolina were recorded. Study sites included frequently and infrequently flooded areas within the floodplains of a small and large river. Within the first growing season, most germinants died; however, those germinating early in the season had greater survival than did later germinants. Mortality declined as seedlings aged through their second year. Oaks had higher survival but fewer new germinants than did most other species. Because new establishment balanced mortality, populations were relatively stable throughout the study period. In all forests combined, oaks comprised 33 percent of the tree basal area but only 14 percent of the seedlings alive in fall 1989. Greater seedling densities and survival were found in the wetter sites.

Introduction

In some forests, seedlings and saplings established in the understories, referred to collectively as advance regeneration, contribute substantially to the development of new stands once the overs tory is damaged or removed (Harper 1977). In southern bottomland hardwood forests, where advance regeneration may account for the majority of new trees after overstory disturbance (Johnson and Krinard 1983), silviculturists commonly survey advance regeneration to predict postharvest stand structure and species composition. However, the development of a more comprehensive understanding of bottomland hardwood forest dynamics requires more information than simply the responses of advance regeneration to disturbance. Patterns of advance regeneration establishment and survival, and conditions that affect these patterns must be known before long-term forest dynamics can be accurately modelled.

While a number of studies have documented effects of stand manipulations on advance regeneration in southeastern bottomland hardwood forests (Johnson and Krinard 1983, Hodges and Janzen 1987, Chambers and Henkel 1989), relatively few investigations have determined dynamics of advance regeneration populations in undisturbed forest understories. Streng et al. (1989) studied seedfall, seed germination, seedling growth and seedling mortality for 5 years in a Texas floodplain forest.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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They divided tree species into two response groups based on life history characteristics. Light-seeded species dispersed high numbers of seeds, germinated early in the growing season, had high population turnover, and had relatively instable seedling populations from year-to-year. Heavy-seeded species germinated later and had more stable seedling populations. Environmental stresses, especially flooding and drought, were major causes of seedling mortality.

The goal of this study was to examine the population dynamics of tree seedlings in the understory of four closed-canopied bottomland hardwood forests in South Carolina. Specific objectives were to identify within- and between-year patterns of germination and mortality, to measure stability of populations in time and space, and to identify important environmental factors that are correlated with population dynamics.

Methods

The study was initiated in four oak-gum bottomland hardwood forests located at the Savannah River Site, an 800 km^2 area in South Carolina controlled by the U.S. Department of Energy. Two forest sites were located within the floodplain of Upper Three Runs Creek, a small Coastal Plain stream with a mean flow of 7.5 m^3s^{-1}. One site, designated the small river flooded (small flooded) site, floods almost every year, usually during late winter and early spring. The other site, designated the small river unflooded (small unflooded) site, rarely floods. Soils at both sites are in the Johnston series, a Cumulic Humaquept. Two additional sites, designated large river flooded and large river unflooded (large flooded and large unflooded) were located within the floodplain of the Savannah River, a stream with a mean flow of 295 m^3s^{-1} and a drainage basin that includes Mountain, Piedmont, and Coastal Plain Provinces. Flooding is annual at the large flooded site and rare at the large unflooded site. Soils at the large flooded site are of the Chewacla series, a Fluvaquentic Dystrochrept; soils at the large unflooded site are Buncombe series, a Typic Udisamment. All four sites were partially cut just prior to federal acquisition of the land in 1950. Since 1950, no tree harvests have occurred on these sites.

Five 25 x 25 m quadrats were randomly located in each site during January-March 1987. In November 1987, species and diameter at 1.3 m (dbh) of all trees (dbh $\geq$ 2.5 cm), and species of all saplings (woody stems $\geq$ 1 m tall but < 2.5 cm dbh) were recorded in each quadrat.

Square plots, each 1 m^2 in size, were randomly located in each quadrat to record seedling dynamics. Prior to spring 1987, seven seedling plots per quadrat were established in the large flooded, small flooded and small unflooded sites (35 seedling plots/site). At the large unflooded site, where seedling densities were relatively low, fifteen seedling plots/quadrat (total of 75) were established. At the end of summer 1987, when it was clear that the small unflooded site also had low seedling densities, eight more seedling plots/quadrat were established at that site. By fall 1987, the study had a total of 220 seedling plots.

Prior to new seedling germination in spring 1987, numbered aluminum tags, 2 X 3.5 cm in size, were loosely attached by thin wires to the bases of all woody seedlings less than 1 m tall in the seedling plots. Woody stems of sprout origin were not tagged; however, many of the tagged lianas of pre-1987 origin were probably produced vegetatively by runners or layering.

When germination first began in spring 1987 and spring 1988, periodic surveys were initiated in order to tag all new germinants. During the first part of the 1987 and 1988 growing seasons, the surveys were conducted every 2-3 weeks. Later in the 1987 and 1988 growing seasons when new germinants were rare, intervals between surveys were increased to 4-5 weeks. No surveys were made during the leafless period (late fall and winter). In 1989, seedlings were surveyed once in spring and once in fall. During spring 1989, only previously tagged seedlings were surveyed; new germinants were not tagged. In fall 1989, all tagged seedlings were surveyed and surviving 1989 germinants were tagged.

For each tagged seedling, records were kept on species, size and general condition (e.g., whether grazed, damaged by insects, bent over, buried by debris, uprooted, wilted, or leafless). A seedling was recorded as dead on the date that the seedling's shoot and root systems were obviously dead, an easy determination to make for some new germinants. However, in many cases seedling mortality was uncertain because the health of the root system could not be determined or the seedling could not be found. When mortali ty was uncertain, the seedling was counted as dead if it remained missing or without new shoot development for three successive surveys. The date of death in the latter circumstance was recorded as the first date that the seedling was missing or without a living shoot.

During the 1987 growing season, one seedling plot at both the large flooded and large unflooded sites had too many new seedlings to tag without damaging some seedlings (i.e., tags could not fit between seedlings). At the large flooded plot, approximately 200 sweetgum (Liquidambar styraciflua L.) were not tagged; at the unflooded plot, approximately 30 hawthorne (Crataegus marshallii Eggl.) and 50 supple-jack [Berchemia scandens (Hill) K. Koch.] were not tagged. Thus, seedling densities at these two sites were slightly underestimated. By fall 1988, all living, previously untagged seedlings in these two plots were tagged; however, because specific dates of origin were unknown, these seedlings were not included in survival analyses. Survival was analyzed by comparing estimates of the survival function, a value that represents the probability that an individual will survive to a particular time. Because the data are right censored, that is, some of the seedlings survive longer than the study period, the Kaplan-Meier product limit method of estimating survival function was used and the resultant survival curves were compared for statistical differences by Wilcoxon and log-rank tests (Lee 1980). The product limit method accommodates unequal time intervals between survey dates, and it allows for estimation of approximate standard errors and confidence intervals (Fox 1989; SAS Institute Inc., 1985).

Between July 1987 and March 1989, water levels were measured approximately bimonthly in PVC-pipe water table wells established at each quadrat center (five per forest site). At each survey date, the percent of each 1 m^2 seedling plot that was covered by water was visually estimated. Between June 1987 and March 1989, soil oxidation-reduction potentials were measured bimonthly using 18 platinum-tipped redox probes per site, as outlined by Patrick and DeLaune (1972). On September 8, 1987, December 2, 1987, and March 30, 1988, dry mass of forest litter (organic debris less than 1 cm in diameter and located above the mineral soil surface) was determined from a sample of 35 systematically located 0.25 m^2 plots. Each litter sample date had a different set of sample plots.

Results And Discussion

Plant Community Profiles

The four sites had relatively similar species composition in the overstory although some differences in dominant species occurred (Table 1). Trees common to two or more sites included laurel oak (*Quercus laurifolia* Michaux), water oak (*Q. nigra* L.), sweetgum, swamp tupelo [*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.] and red maple (*Acer rubrum* L.). Sapling density was greater in the small than in the large river sites. Within river systems, saplings were more abundant in unflooded sites (Table 1), a trend noted in other floodplains and attributed to differences in the amount of flood-induced mortality (Conner et al., 1990). Sapling canopies were dominated by two life forms: shrubs such as Virginia-willow (*Itea virginica* L.) and blueberry (*Vaccinium elliotii* Chapm.); and small tree species such as Carolina ash (*Fraxinus caroliniana* Miller) and redbay [*Persea borbonia* (L.) A. Sprengel]. Large tree species, such as laurel oak and sweetgum, comprised 30 percent or less of all saplings (Table 2). Seedling densities were high (range 78,000 to 406,600 per ha) ; however, most of these were very small (mean height in fall 1989 was 14.1 cm; standard deviation was 12.3 cm). Within river flooplains, seedlings were two to three times more abundant in frequently flooded than in rarely flooded sites (Table 1). In all but the large unflooded site, seedling canopies were dominated by species in the large tree life form (Table 2). Lianas were a substantial part of the total seedling canopies of the large river sites (Table 2).

Within-year Dynamics

During the 1987 and 1988 growing seasons, germinants began emerging in early April and late March, respectively. Most germination occurred during 60 days following the first emergence (Fig. 1). The small differences between sites in the timing of peak of germination (Fig. 1) were related to species composition and timing of germination within species. For example, sites with many sweetgums tended to have an earlier peak compared with those with many red maples. Sweetgum had a study-wide peak in germination 2 weeks before red maple in 1987 and 5 weeks before in 1988. However, in 1988 the red maple peak at the small unflooded site occurred 2 weeks after the red maple peak at the large flooded site. Streng et al. (1989) reported similar patterns in a bottomland hardwood forest in Texas where germination was concentrated in the early half of the growing season and the peak of red maple germination was well after that of most other species.

All germinants were divided into within-year cohorts with each cohort corresponding to all new germinants found and tagged at a particular date. In both 1987 and 1988, all within-year cohorts had considerable early mortality followed by a steady decline in absolute mortality (Fig. 2). In most cases, cohorts emerging earlier in the growing season had greater survival than did later cohorts, both at the end of the first growing season and by fall of 1989 (Fig. 2). Except for high survival of the last cohort

Table 1. Woody plant densities measured fall 1987 (tree and sapling canopies) and fall 1989 (seedling canopy).

Species*	Tree Basal area	No. saplings	No. seedlings
	$m^2\ ha^{-1}$	no. ha^{-1}	(no. ha^{-1}) x 1000
Small river flooded			
Quercus laurifolia	9.52	92.8	62.6
Nyssa sylvatica var. biflora	8.30	83.2	39.7
Fraxinus caroliniana	6.80	281.6	5.7
Liquidambar styraciflua	6.29	80.0	100.9
Taxodium distichum	3.30	22.4	1.1
Acer rubrum	1.53	48.0	152.6
Betula nigra	1.11	3.2	5.1
Others	0.75	476.8	38.9
Total	37.60	1088.0	406.6
Small river unflooded			
Nyssa sylvatica var. biflora	8.74	48.0	-2.0
Liquidambar styraciflua	5.05	16.0	12.9
Magnolia virginiana	4.00	67.2	4.8
Ilex opaca	3.10	441.6	14.0
Quercus michauxii	2.78	12.8	4.4
Quercus nigra	2.29	9.6	28.3
Acer rubrum	1.98	9.6	
Persea borbonia	1.81	1132.8	3:::
Liriodendron tulipifera	1.65	0.0	0.7
Fagus grandifolia	1.40	3.2	0.1
Quercus laurifolia	1.27	6.4	3.3
Others	0.13	1017.6	20.1
Total	34.20	2764.8	129.6
Large river flooded			
Quercus laurifolia	11.33	0.0	0.8
Liquidambar styraciflua	9.76	3.2	36.3
Acer rubrum	5.72	0.0	34.0
Ulmus americana	0.88	0.0	3.4
Fraxinus pennsylvanica	0.77	0.0	0.0
Quercus lyrata	0.66	0.0	0.0
Carya aquatica	0.59	0.0	0.0
Others	2.49	41.6	65.2
Total	32.20	44.8	139.7
Large river unflooded			
Quercus nigra	10.32	0.0	0.4
Liquidambar styraciflua	4.20	0.0	3.7
Quercus pagoda	4.17	0.0	0.9
Pinus taeda	3.74	0.0	1.2
Ulmus alata	1.76	48.0	0.5
Quercus laurifolia	1.56	0.0	0.4
Ilex opaca	0.90	3.2	3.5
Carpinus caroliniana	0.82	3.2	10.7
Quercus michauxii	0.69	3.2	0.0
Carya cordiformis	0.47	0.0	0.4
Others	0.97	707.2	56.3
Total	29.60	764.8	78.0

* Plant nomenclature follows Brown and Kirkman (1990).

Table 2.-Percent of woody stems by life forms within the sapling and seedling canopies. Large and small tree species are those that frequently exceed 30 cm and 5 cm dbh, respectively.

	Site			
	Small river		Large river	
Life form	Flooded	Unflooded	Flooded	Unflooded
---------------- Sapling canopy ----------------				
Large tree	6.3	30.3	21.4	7.5
Small tree	56.9	36.2	78.6	33.1
Shrub	36.8	33.5	0.0	59.4
---------------- Seedling canopy ----------------				
Large tree	89.2	45.0	63.4	11.4
Small tree	2.5	40.1	4.1	21.2
Shrub	6.2	11.1	0.4	5.3
Liana	2.1	3.5	32.1	62.1
unknown	0.0	0.3	0.0	0.0

in 1987, the pattern of greater survival of early cohorts was consistent for both years, all four sites, and all major species. Rapid mortality early in the growing season followed by reduced absolute mortality has been reported frequently for tree seedlings in forest understories (Hett and Loucks 1971, 1976; Streng et al., 1989). However, the greater propensity of early germinants to survive compared with later germinants has been noted rarely (Trimble and Tryon 1969; Streng et al., 1989). Streng et al. (1989) found that the date of emergence had a stronger effect on seedling mortality than did flooding or light levels in an East Texas floodplain forest. Hypotheses to explain higher survival of early germinants include better growing conditions (e.g., more light) during the early part of the growing season and a correlation between emergence time and seed vigor (Streng et al., 1989; Jones and Sharitz 1990).

Between-year Dynamics

When seedlings were divided into annual cohorts representing those germinating during and still alive by the fall of a particular growing season, a pattern of steadily decreasing mortality with age appeared (Fig. 3). For example, between fall 1988 and fall 1989, seedlings that germinated in the years prior to and including 1986 ($\leq$ 1986), had much lower mortality than did seedlings germinating in 1987. Furthermore, the 1987 cohort had lower mortality than did the 1988 cohort during fall 1988 to fall 1989 (Fig. 3). Streng et al. (1989) reported a similar decrease in mortality as seedlings aged, especially between the first and second year after germination.

Survival of annual cohorts differed according to species and site. Oaks had relatively high and American holly (*Ilex opaca* Aiton) low survival in most annual cohorts (Fig. 4). However, species differences were not consistent. Sweetgum in the 1987 cohort had lower survival than did red maple, yet sweetgum and red maple had similar patterns of survival in the other annual cohorts (Fig. 4).

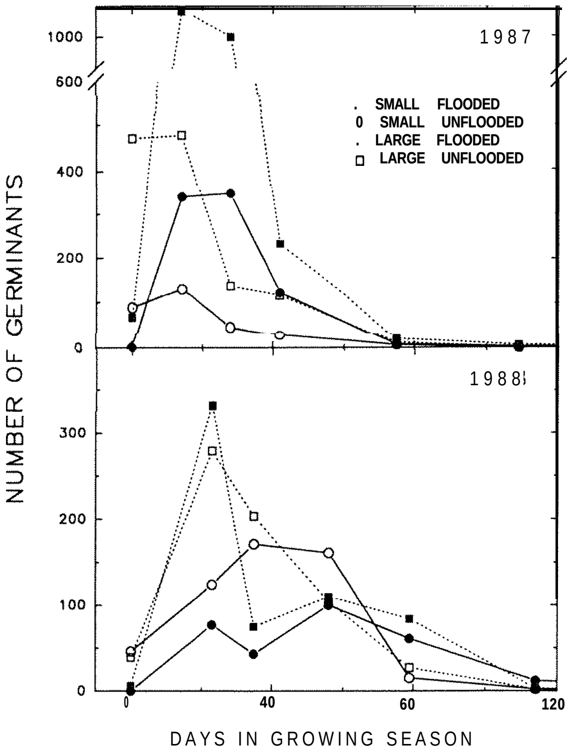

Figure 1. Number of new germinants on seedling plots during 1987 and 1988 growing seasons.

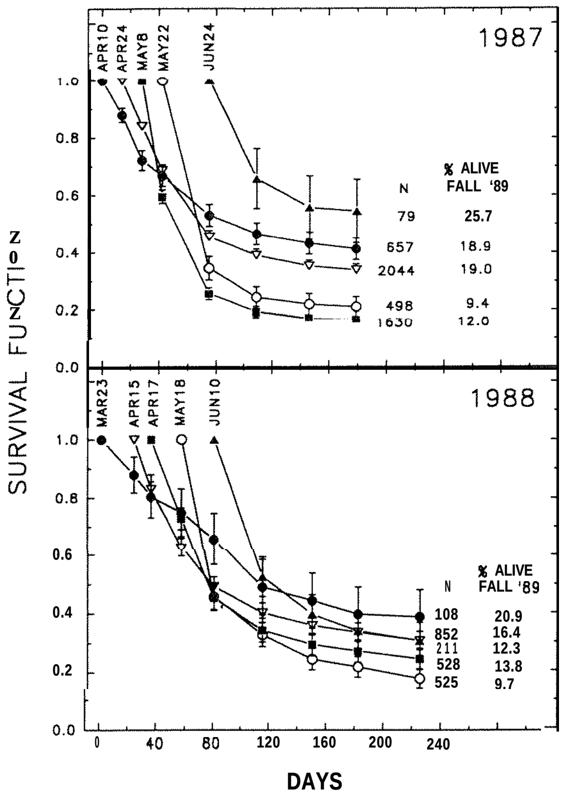

Figure 2. Survival of within-year seedling cohorts for all species combined. Dates are when cohorts were first identified and tagged. Error bars are 95 percent confidence interval estimates. Within years, curve shapes are significantly different according to Wilcoxon and log-rank tests ($P < 0.001$; df = 4).

Differences between sites in seedling survival were not consistent across cohorts. For example, the small flooded site had relatively high survival in the ≤1986 and 1987 annual cohorts, but only intermediate survival in the 1988 cohort (Fig. 5) Although differences in species composition may have led to some of the site differences (e.g., the high survival of the samll river (1986 cohort was partly due to an abundance of oaks at that site), site differences held within species. For example, in the ≤1986 sweetgum cohort, 50 out of a total of 67 seedlings (74.6 percent) at the large flooded site died between fall 1987 and fall 1989; only 111 out of 337 (32.9 percent) died at the samll flooded site during that same period.

Correlation of seedling densities on each plot in fall 1987 with densities in fall 1989 show a high degree of population stability, for all seedlings combined and for individual species (Table 3). Fall seedling populations over the 3-year study were 3,682 in 1987, 3,396 in 1988, and 2,795 in 1989. Oaks, because of their high survival rate, were extremely stable. In addition to fall-to-fall stability between years, spring-to-fall stability within the same

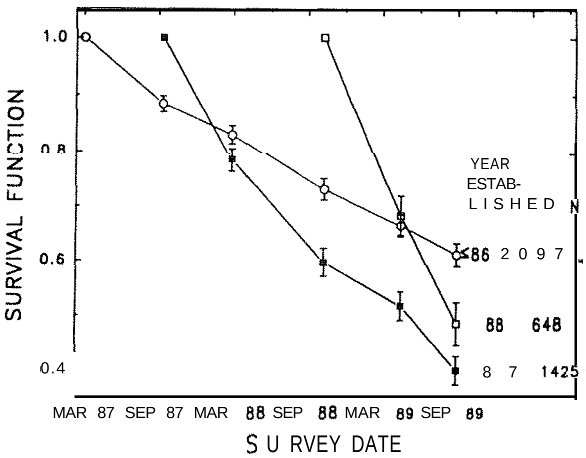

Figure 3. Survival of annual seedling cohorts for all species and sites combined. Error bars are 95 percent confidence interval estimates. Curve shapes are significantly different according to Wilcoxon and log-rank tests ($P < 0.001$; df = 2).

growing season was relatively high (Table 3), despite the large turnover of seedlings during the first part of the growing season and the large number of germinants in 1987 and 1988 (5,062 and 2,326, respectively). Apparently, mortality was relatively well balanced by germination of new seedlings throughout this study. Thus, relatively similar estimates of population density could have been made no matter what time of year the survey was made and no matter which year the survey was made. Seedling numbers are generally lower in fall than in spring or summer; thus, fall surveys will result in a conservative estimate of seedling densities.

If the stability of seedling populations in this study is indicative of most bottomland hardwood forests, silviculturists could survey advance regeneration and have some confidence that the survey would provide a reasonable estimate of population density and potential

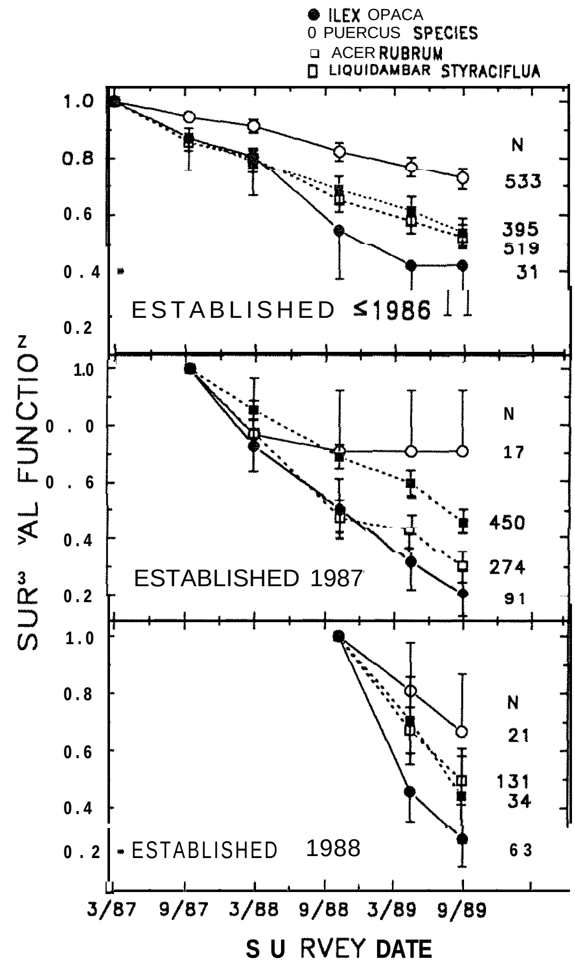

Figure 4. Survival of annual seedling cohorts for four species with all sites combined. Error bars are 95 percent confidence interval estimates. For seedlings established before or during 1986, curve shapes are significantly different according to Wilcoxon and log-rank tests ($P < 0.001$; df = 3). Tests were not applied in 1987 and 1988 seedlings because of small sample sizes.

regeneration success for one or more years. However, populations may not be as stable as in this study. Streng et al. (1989) found that over a 5-year period, fall seedling populations of common spe-

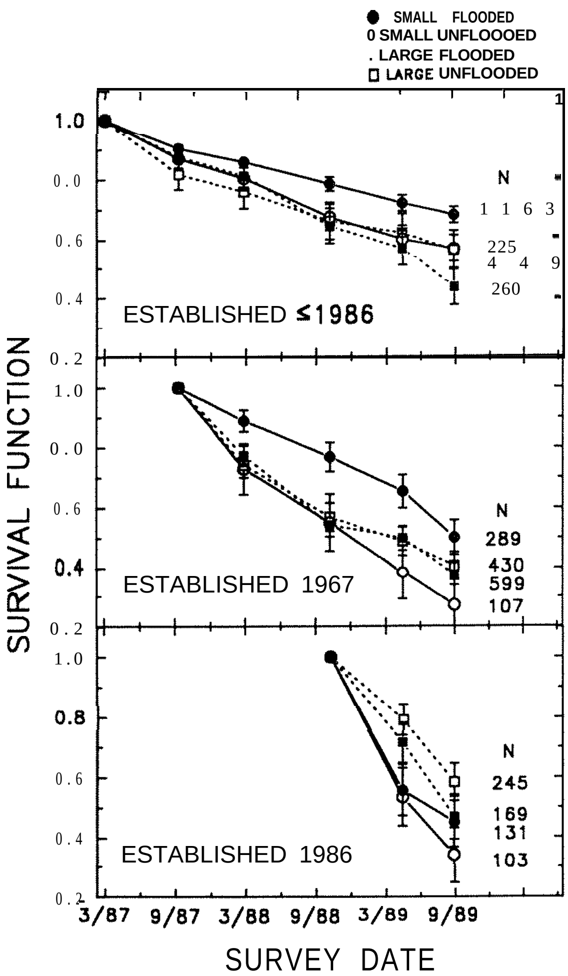

Figure 5. Survival of annual seedling cohorts for four sites with all species combined. Error bars are 95 percent confidence interval estimates. Within each year of establishment, curve shapes are significantly different according to Wilcoxon and log-rank tests ($P < 0.001$; df = 3).

cies on permanent plots ranged from 615 to 1812, with most of population fluctuation occurring among light-seeded species such as sweetgum, deciduous holly (Ilex decidua Walter), and American hornbeam (Carpinus caroliniana Walter). Oak populations in Streng's study, however, remained relatively stable.

Oak Regeneration

Oaks comprised between 19 and 57 percent of the total tree basal area but much less of the sapling density at each site (Table 4). Oak seedling density was relatively high in the small river sites and low in the large river sites. Most oak seedlings were 1986 or younger germinants of laurel and water oak. Despite small numbers of new germinants during 1987-1988, oaks maintained large populations in the small river sites, chiefly because of greater survival (Table 4) and apparent large germination events some time before this study was initiated.

Correlation of Environment with Population Dynamics

Within river systems, flooded sites had lower oxidation-reduction potentials, more surface flooding, and shallower water tables (Table 5). However, compared with the large river sites, the two small river sites had shallower and less variable water tables as well as lower surface litter mass, indicators that more favorable soil moisture conditions may exist at the small river sites during the growing season. Since seedling populations were much denser in flooded than in unflooded sites within river systems (Table 1), and denser in the small than in the large river system, both flooding and summer soil moisture may enhance seedling population development, either through greater numbers of germinants or higher seedling survival. Experiments are needed to determine how soil moisture and flooding may be related to seedling germination and survival.

Table 3. Stability of seedling populations expressed as number of living seedlings per m^2 in fall 1987 correlated with number per m^2 in fall 1989 (fall stability) or number per m^2 in spring and fall of the same year (spring-fall stability).

Comparison	Correlation coefficient (r)	Number of m^2 plots*
	---------- Fall stability ----------	
All species	0.91	220
Liquidambar styraciflua	0.81	163
Acer rubrum	0.92	123
Ilex opaca	0.43	103
Quercus laurifolia	0.99	63
Quercus nigra	0.99	46
	---------- Spring-fall stability ----------	
All species		
May 8 vs. October 6, 1987	0.79	180
April 27 vs. November 2, 1988	0.95	220

* To prevent inflation of correlation coefficients, plots where no seedlings were found on both dates were dropped from analysis.

Table 4. Oak attributes as a percent of the total forest.

At tribute	Site: Small river, Flooded	Site: Small river, Unflooded	Site: Large river, Flooded	Site: Large river, Unf looded
	-------- percent		--------	
Total tree basal area	25	19	37	57
Sapling density	9	1	0	< 1
All seedlings alive in fall 1989	17	32	1	1
All 1987 germinants	< 1	4	< 1	1
All 1988 germinants	1	2	1	1
Relative seedling survival*	196	219	288	100

* (percent survival of oak seedlings divided by percent survival in all other species) x 100.

Conclusions

In the four bottomland hardwood forests of this study, tree seedling germination and mortality were greatest during the first 60 days of each

Table 5. Key environmental data.

At tribute	Number of Surveys	Samples per Surveys	Small river Flooded	Small river Unfl.	Large river Flooded	Large river Unfl.
Water table depth (cm) below soil surface	42	20	21.8 (16.6)*	23.4 (13.9)	31.7 (26.3)	153.6 (24.1)
Redox potential (mV) at 15 cm soil depth	43	72	189 (127)	300 (79)	182 (146)	567 (52)
Percent of soil surface flooded	20	180-200	11.1 (29.3)	0.0 (0.0)	7.3 (23.6)	0.0 (0.0)
Litter mass (g m^{-2})						
September 1987	1	140	503 (271)	510 (125)	809 (370)	1014 (362)
December 1987	1	140	790 (163)	782 (240)	840 (265)	967 (187)
March 1988	1	140	796 (185)	860 (458)	913 (307)	1088 (269)

* Numbers in parentheses are standard deviations.

growing season. Within growing seasons, those seedlings that germinated early had higher survival. Survival increased after the first growing season up through 2 years of age. The best time to assess advance seedling populations is in late summer or early fall when leaves are still on the seedlings, germination rates are low or zero, and mortality rates are relatively low. Populations remained highly stable from fall to fall in this study; thus, a survey in fall of 1 year may be a good approximation of advance seedling populations for some years afterward. Compared with other species, oaks had fewer germinants but higher survival. Periodically, larger germination events may occur which leave behind a stable population of oaks that persists for many years after germination. Correlations of environmental data with population dynamics indicated that wetter sites may have higher seedling survival.

Acknowledgments

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GROWTH AND SURVIVAL OF ATLANTIC WHITE-CEDAR ON A SOUTH CAROLINA COASTAL PLAIN SITE-- FIRST YEAR RESULTS [1]

Marilyn A. Buford, Claire G. Williams, and Joseph H. Hughes [2]

Abstract. A 0.8-ha test planting of Atlantic white-cedar (Chamaecyparis thyoides) rooted cuttings was installed on the Francis Marion National Forest in July 1989. The soils at the planting site are classed as Pamlico muck. Planting density was 2.4 x 2.4 m (1680 trees/ha). Survival was 99, 93, and 90 percent after 2, 7, and 16 months, respectively. Average height of the surviving stems was 30.6 and 37.6 cm after 7 and 16 months, respectively. The average height of trees that were standing in water was 8.5 cm less than that of trees not standing in water. It is expected that this research will ultimately provide techniques and information to successfully regenerate lower Coastal Plain wetland areas with an ecologically adapted, high-value species.

Introduction

Under current policy and regulations, wetlands lost through any activity must be restored or new wetlands must be created to take their place. Once a suitable wetland hydrological regime is created or restored, vegetation must be matched with the site to ensure a functioning forested wetland. Atlantic white-cedar (Chamaecyparis thyoides (L.) B.S.P.) is an obligate wetland species whose natural botanical range extends along the Atlantic coast from southern Maine to northern Florida and across the gulf coast through Mississippi. Atlantic white-cedar is valuable as a source of decay resistant wood products and is potentially valuable in wetlands restoration and creation. There is little or no information available on the growth and survival of the species on the lower Coastal Plain of South Carolina. Experimental plantings of the species have been and are currently being made in the Southeastern United States, but many questions regarding its culture remain unanswered. This paper reports the lst-year growth and survival of Atlantic white-cedar planted on an organic soil near Awendaw, South Carolina. The information will be useful to those charged with creating or rehabilitating a forested wetland and to public and private landowners searching for alternative wetland forest crops.

Objectives of this study are to: (1) determine the survival and growth rate of Atlantic white-cedar rooted cuttings planted on an organic soil on the lower Coastal Plain of South Carolina, and (2) begin

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evaluating the suitability of Atlantic white-cedar for wetlands restoration and creation, and as an alternative cash crop on wet sites on the lower Coastal Plain.

Literature Review

The botanical range of Atlantic white-cedar extends from Maine to Mississippi, but the commercial range historically has been restricted to southeastern New Jersey, the freshwater swamps of Virginia and North Carolina, and the large river swamps in southern Alabama and western Florida (Korstian and Brush 1931). Large stands of the species were reported in the South Carolina counties along the Fall Line, and in at least two coastal counties (Frost 1987, Laderman 1989). Records also indicate that some small stands occur in the Francis Marion National Forest on the lower Coastal Plain of South Carolina (Laderman 1989), but their exact location is unclear. The abundance of the species has been significantly reduced during the last 200 years primarily due to disruption of the hydrological cycle, conversion of cedar sites to agriculture, improper harvest and regeneration procedures, and fire suppression (Tangley 1984, Earley 1987, Frost 1987). Atlantic white-cedar generally occurs in pure stands in areas of peat underlain by sandy subsoil. It occurs in mixed stands with red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), and sweetgum (*Liquidambar styraciflua* L.) on peat or sand underlain by more clayey deposits (Korstian and Brush 1931, Little 1950, Laderman 1989). At the southern extreme of its range, stands occur on sandy beds adjacent to streams (Schroeder and Taras 1985, Clewell and Ward 1987). Generally, stands occur in acid conditions with soil and water pH ranging from 2.5 to 6.7 (Day 1984, Golet and Lowry 1987, Schneider and Ehrenfeld 1987, Whigham and Richardson 1988, Laderman 1989). Higher pH values have been recorded for Atlantic white-cedar stands in Florida (Collins et al., 1964; Clewell and Ward 1987). Essentially all of the literature are characterizations of remnant natural stands. Examples of Atlantic white-cedar stand creation are rare. Research on stand creation and evaluation of these attempts is needed (Laderman 1989).

Methods

Site Description

The test site is in Berkeley County, South Carolina, in Compartment 185 of the Wambaw Ranger District, Francis Marion National Forest. The planting site is on the north side of Road 33, approximately ½ mile NW of the intersection of County Line Road (SC 98) and Awendaw Road (SC 133), in an area known as Ocean Bay. The area was burned in a hot wildfire in 1987.

The soils are classed as Pamlico muck. Soil borings in the area indicate organic matter to a depth of 0.9 to 1.5 m, with a fine sand-organic matter composite below that. The water table appears to be within 0-30 cm of the surface most of the year.

The existing vegetation cover is a mixture of redbay (Persea borbonia (L.) Spreng.), fetterbush (Lyonia lucida (Lam.) K. Koch), Sweet bay (Magnolia virginiana L.), laurel-leaved greenbriar (Smilax laurifolia L.), loblolly-bay (Gordonia lasianthus (L.) Ellis), and pond pine (Pinus serotina Michx.).

Plant Material

Weyerhaeuser Company provided 1000 Atlantic white-cedar rooted cuttings. The rooted cuttings were produced at its nursery in Comfort, North Carolina, from material taken from wild seedlings on their land north of New Bern, North Carolina. The cuttings were received in late April 1989, and held out-of-doors in 23-m planting tubes until planted July 17-18, 1989. While held in the planting tubes, the cuttings were watered every 3 to 5 days and one fertilizer treatment (20-20-20 N-P-K house plant fertilizer) was applied in mid-June. At the time of planting, the average height of the cuttings was 20-25 cm.

Site Preparation and Layout

An area 75.6 x 78.0 m was cleared using hand-held, gasoline-powered brush cutters equipped with brush blades. On the recommendation of Joe Hughes, a planting density of 1680 trees/ha (square spacing of 2.4 x 2.4 m) was used. Each planting position was marked with a pin flag. The test area is 31 x 32 rows (0.6 ha), and 992 trees were planted on the area. Deer repellant was used as a precaution.

Measurements

Survival was recorded at the end of the first growing season--after the cuttings had been in the field for 2 months. Survival and height of each cutting was recorded at the beginning and at the end of the 1990 growing season. During the second growing season, it was observed that those trees standing in water did not appear to be as vigorous as those not standing in water. Therefore, whether or not the tree was standing in water at the time of the last measurement was recorded. At the end of the second growing season, pH of the surface water was measured.

Results And Discussion

The cuttings were outplanted only 2-3 months before the end of the growing season in 1989. The planting site was impacted by Hurricane Hugo. Although there was no salt water intrusion, the location and the drainage pattern on the site suggest that the plants were submerged by rainwater for approximately 1 week after the storm. There was no apparent wind damage. Survival at the end of that partial growing season was 99 percent. Surface water pH at the end of the 1990 growing season was 3.4. There was no indication of herbivory and no deer or deer sign were seen in the area.

Survival and height at the beginning and end of the 1990 growing season are given in Table 1. The negative increment in minimum height from spring to fall results from dieback and resprouting, which were observed on several of the trees. The distribution of heights at the beginning and end of the second growing season are given in Figure 1. The height distribution is shifting to the right with time, as expected.

Table 1. Survival and height of Atlantic white-cedar rooted cuttings after one and two growing seasons.

Date	Survival	Mean Height	Minimum Height	Maximum Height
	(%)	----------------	(cm)----------	----------------
Feb. 1990	93.4	30.6	15.2	51.8
Oct. 1990	89.8	37.6	10.2	75.6

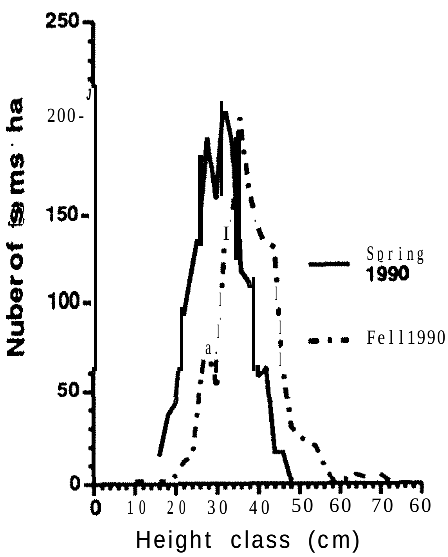

Figure 1. Number of stems/ha by 2-cm height class before and after the 1990 growing season in an Atlantic white-cedar test planting in South Carolina.

Average height of those trees standing in water was 29.2 cm; 8.4 cm less than the stand average. The differences in average height were not statistically significant at α = 0.05. Maximum height of those trees was 37 cm; less than half the stand maximum. It is not clear whether these trees simply grew more slowly than the others or suffered multiple diebacks. These results are similar to observations on naturally regenerated seedlings occurring on small hummocks, which appear to grow and survive better than those in depressions.

Conclusions

Although these early results cannot be conclusive, the 89.8 percent survival and good height growth of the Atlantic white-cedar rooted cuttings indicate that the species may be planted successfully on similar organic soils in wetlands restoration and as a wet site crop. There was an apparent difference in height growth between trees that were and were not standing in water. Those standing in water were 23 percent shorter than the trees not in water. These height differences may be of practical significance in the culture of the species and will be important to follow.

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A REGION-WIDE STUDY TO MODEL LOBLOLLY PINE GROWTH RESPONSE TO DEGREE AND TIMING OF HARDWOOD CONTROL AND HERBACEOUS WEED CONTROL [1]

Dwight K. Lauer, and Glenn R. Glover [2]

Abstract. A region-wide pine release study is currently being installed in the Southeastern United States by the Auburn University Silvicultural Herbicide Cooperative. The primary objective of the study is to quantify the pine growth responses to the degree and timing of woody vegetation control in loblolly pine plantations. The study uses a response surface approach in which locations are selected to provide information on specific combinations of factors. Variation is reduced at each location by the sampling and matching of plots on the basis of both pine and hardwood attributes. Herbaceous weed control combined with hardwood control is included as a treatment at most locations. Pines, hardwoods, shrubs, and herbaceous weeds are measured in the establishment year, then periodically thereafter. A summary of the 52 active locations is given.

Introduction

The term "release" is often confusing to foresters. Release of loblolly pine (*Pinus taeda*) in the Southeastern United States can be subdivided into three different, though not mutually exclusive, practices: "weeding," "cleaning," and "liberation." Cleaning and liberation involve the removal of hardwoods before the trees are past the sapling stage (Smith, 1962). Cleaning refers to the removal of hardwoods originating from seed or sprouts from the time of stand establishment. Liberation refers to the removal of overtopping hardwood residuals left at harvest. Weeding is the control of herbaceous weeds.

A range of herbicide techniques has been developed over the last decade for release. Broadcast cleaning can be done with imazapyr, glyphosate, and hexazinone. Directed cleaning applications can be done using directed foliar sprays of triclopyr, imazapyr, or glyphosate, or using basal bark treatments of triclopyr or imazapyr. Weeding can be done with sulfometuron methyl, hexazinone, imazapyr, glyphosate, atrazine, or various combinations of these.

Response from operational cleaning is often difficult to estimate because of the many factors involved. The treatment chosen can be dependent on stand age. Broadcast treatments will have some level of herbaceous weed control associated with them, directed applications will not. Rates are selected to provide crop tolerance and achieve acceptable but not complete hardwood

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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control. Response will also be related to the level and composition of hardwood present at the time of cleaning. Installing studies to quantify growth using the many available techniques and herbicides across the extensive range of sites and hardwood species composition would be unreasonable if not impossible.

In 1984 the Auburn University Silvicultural Herbicide Research Cooperative, a forest industry, state, Forest Service, and University cooperative, installed the first location of a study designed to quantify the effects of degree and timing of woody vegetation control along with the effects of weeding that are often associated with cleaning. After the 1989-90 installation-season there was a total of 52 locations across the Southeast (Fig. 1).

Study Design

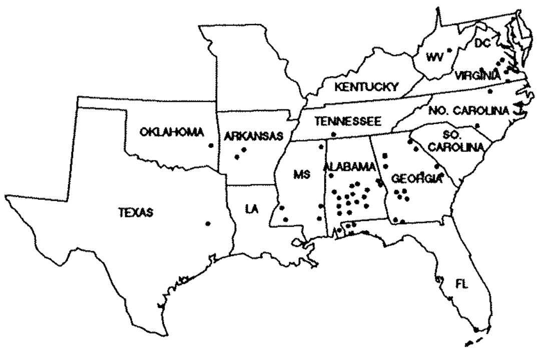

Figure 1. Geographic locations of 52 study sites in the Southeastern United States.

An important objective of this study is to model response over a range of site index, treatment ages, and hardwood levels. More emphasis is on general trends across management units than on specific site responses. Although treatments consist of percentage hardwood reductions, the initial hardwood density that determines the actual treatment level is not created, but sampled, and can be highly variable within a stand. Blocking of replicated treatments could help reduce variation among treatments, but there are practical limitations to the number of plots that can be placed in a given stand. Conditions can differ enough among blocks in vegetation studies to result in large variations of treatment responses among blocks. Very often it is difficult to replicate precise hardwood treatment levels, especially when treatments involve partial reductions, due to variation in initial hardwood conditions and treatment efficacy.

For these reasons, a regression response surface approach is being used for the location, treatment allocation, and analysis of this study. Treatments are not replicated at given location, but variation among the five plots at a location is reduced by the pre-sampling and matching of plots on the basis of pine stocking (±10 percent), pine height (±10 percent), and hardwood density (±20 percent) pretreatment. Post-treatment levels are targeted in the design matrix but differences in initial conditions and treatment efficacy are overcome by the use of actual post-treatment levels of vegetation and by the retreatment of the 100 percent hardwood reduction treatments 1 year after the initial treatment.

Selected sites are primarily mesic sites where the primary hardwood species are oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua*), hickories (*Carya* spp.), blackgum (*Nyssa sylvatica*), and maples (*Acer* spp.).

Fertilized or flatwoods sites are avoided. There are no restrictions on site preparation methods except that the method must allow for proper plot installation, and that chemically prepared site areas should be at least 2 years old so there are no active herbicide effects that might influence hardwood assessments. Allowable pine stocking is a maximum of 900 trees/ac and a minimum of 500, 450, 400, and 350 trees/ac for ages 0, 1, 2 or 3, and 4 or 5, respectively.

A design matrix was created using low, medium, and high site index classes (< 55 ft, 55-64 ft, and > 64 ft at age 25, respectively), pine ages 0 through 5, and the four hardwood density classes defined in Table 1. These combinations yield a total of 72 initial-condition data cells. Since specific combinations are more important than others, and some combinations might not exist, emphasis was given to the medium site index level, ages l-3, and initial hardwood levels B-D. Thus, some combinations are not represented in the data matrix, while other more important combinations could be represented by as many as three locations. The emphasis given to particular combinations was based on perceived acreage distribution by site class and vegetation type, and on perceived management trends.

Table 1. Hardwood density classes by plantation age.

Hardwood Density Class	Plantation Age 0	1	2-3	4-5
	Rootstocks/acre			
A	<501	<501	<501	<501
B	501-1000	501-1000	501-1500	501-2000
C	1001-1500	1001-2000	1501-2500	20013000
D	>1500	> 2000	>2500	>3000

Treatment Allocations

After five plots at a location have met specifications, treatments are allocated from the original design matrix based on the pre-sample hardwood level, then randomly assigned to the plots. Treatments consist of an untreated control and four combinations of hardwood reduction and herbaceous weed control. The specific combinations available depend on the initial hardwood density class. The levels of hardwood reduction for different initial hardwood densities are presented in Table 2. A "D" density age-4 site, for instance, can have treatments that reduce hardwoods by 0, 30, 65, 90, or 100 percent. With herbaceous weed control there are a total of 9 possible treatments and an untreated check to allocate to five plots on a "D" density site. Since not all possible treatments can be used at a given location, different combinations of treatments are assigned to locations when there are multiple locations within the same initial condition cell, and some combinations that are not thought to be relevant are discarded. The herbaceous weed control treatments, for instance, are not present at all locations and are assigned more frequently to locations with lower hardwood densities and pine ages O-3.

Hardwood control is accomplished during the dormant season when the study is established, using a basal bark application of triclopyr ester in diesel fuel. Percent reductions are accomplished by randomly selecting rootstocks to spray. Randomization is done with 20 objects (such as marbles) of two colors, in the correct proportion to achieve a given percent

Table 2. Hardwood percent reduction treatments by initial pine age, initial hardwood class, and residual hardwood class.

Initial Pine Aae	Initial Hardwood Class	Residual Hardwood Class 0	A	B	C	D
(years)		(Percent hardwood reduction)				
o-5	A	100%	0%	0%	---	---
O-l	B	100%	65%	0%	---	--
2-5	B	100%	75%	0%	--	---
0	c	100%	80%	40%	0%	---
1	C	100%	85%	50%	0%	---
2-5	C	100%	90%	50%	0%	---
0	D	100%	85%	55%	30%	0%
1	D	100%	90%	70%	40%	0%
2-3	D	100%	90%	70%	35%	0%
4-5	D	100%	90%	65%	30%	0%

reduction, being drawn at random without replacement. The process is repeated for every set of 20 rootstocks across the treatment plot. The arborescent hardwoods are treated, then the scheme is repeated to treat non-arborescent hardwoods (shrubs). The 100 percent hardwood reduction treatment, in which all hardwood stems are treated, is re-treated after 1 year to ensure complete control.

Herbaceous weed control is accomplished with a spring broadcast application of sulfometuron methyl and a June directed application of glyphosate. Herbaceous weed control is not continued after the first year.

Plot design And Pm--sampling

A total of five treatment plots is located and matched on the basis of pine stocking, pine height, and hardwood density. Typically, 120 x 120 ft (0.33 ac) treatment plots are established with an 82 x 82-ft (0.15 ac) pine measurement plot (PMP) centered within. If relatively parallel rows are discernable, plot corners are placed halfway between rows close to 82-ft apart and plot length is adjusted so that PMPs are no smaller than 0.15 ac. Pines on the PMPs are dot tallied by height class to determine the average height and density (trees/ac) for each plot. Plots that are within ±10 percent of the mean average pine height and density are then sampled for hardwood density (rootstock/ac). The hardwood pre-sample is a systematic sample in which hardwood rootstocks are counted on five 6-ft-wide strips within the PMPs (36 percent sample). Plots not within ±20 percent of the mean hardwood density are discarded. Routinely more than five plots are pre-sampled before there are five that meet specifications. These specifications are dependent on the five plots that are being matched.

After matching, PMPs are permanently installed and eight 7-ft-radius (0.0035-ac) competition measurement plots (CMPs) are permanently installed. The original intent of the CMPs was to provide a sample size that made hardwood measurements tenable. Pines are tagged and remeasured on the PMPs and hardwoods and non-arborescent hardwoods are measured on the CMPs. Since hardwood vegetation is very often clumped across the PMP, two CMPs are randomly placed within each quadrant of the PMP to ensure adequate coverage. Because of the large variation in hardwood density and the sometimes small post-treatment sample size, a complete enumeration of all hardwoods on the PMPs is now done 1 year after treatment, at ages 5, 8, 12 and

15, and every 5 years thereafter. Nonetheless, the CMPs are important for the inclusion of more intensive hardwood measurements and for measurements of herbaceous and non-arborescent vegetation.

Five square ¼-milacre herbaceous clip plots are temporarily located, rated, and clipped in August of the establishment year only.

Measurements And Measurement Schedule

Measurements vary by vegetation type and pine age. Early measurements are not done at the same ages for all locations because of differences in establishment age.

Pines and hardwoods are measured during the dormant season in the year of establishment, 2 years after establishment, at ages 5, 8, 11 and 15, and then every 5 years to rotation. Exceptions to this are that age 0 sites are measured after 1 year, and that a 100 percent PMP hardwood tally is done 1 year after treatment. Shrubs, herbaceous vegetation, and percent cover of all vegetation are measured on CMPs in August before dormant season pine and hardwood measurements. Shrubs are also measured at the time of study installation.

Pine measurements include insect and disease condition codes, pine height, and the Virginia Division of Forestry free-to-grow class (Zutter et al., 1985). Dbh and fusiform rust incidence are included at age 5 and older. At age 8, crown class replaces the free-to-grow classification. A subsample of 20 pines in each PMP is measured for diameter at 6 inches aboveground (dah), height to live crown, and crown widths. The dah measurements are not continued after age 5, crown widths are not measured after age 8, and a fusiform stem rust severity code is included at age 5 and older.

Hardwoods measurements are done on both the CMPs and PMPs. Hardwood rootstock crown widths, height class, and species are measured on the CMPs at establishment and 2 years after treatment. Hardwood measurements 1 year after treatment and at age 5 consist of crown widths, height class, and species for all hardwoods on the PMPs and, additionally, the measurement of dbh for hardwoods on the CMPs. Species and crown widths for each hardwood rootstock, and dbh and height class for each stem above 4.5-ft tall, are measured for hardwoods taller than 4.5 ft on the PMP at age 8 and all hardwoods above 0.5 ft tall are measured on the CMPs at age 8. Measurements will be similar after age 8 except that crown widths will not be measured, and the more intensive hardwood measurements on the CMPs will be dropped.

Non-arborescent hardwood measurements include species, percent cover, and mean height. Data are recorded on each CMP plot at establishment, in August of the establishment year, and in August before scheduled pine measurements through age 8.

Herbaceous vegetation is measured in August of the establishment year and in August before scheduled pine measurements through age 8. Percent cover of all herbaceous vegetation and percent cover for the five major genera on the CMPs are recorded. Percent cover estimates of pine, hardwood, shrubs, and bare ground are also recorded. Percent cover and oven-dry weight of all herbaceous vegetation and percent cover for the five major herbaceous genera are measured on the herbaceous clip plots in August of the establishment year.

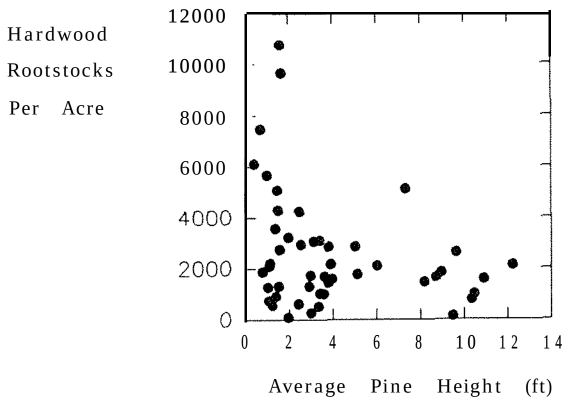

Figure 2. Initial hardwood rootstocks/ac vs. initial average pine height for current RL-4I locations.

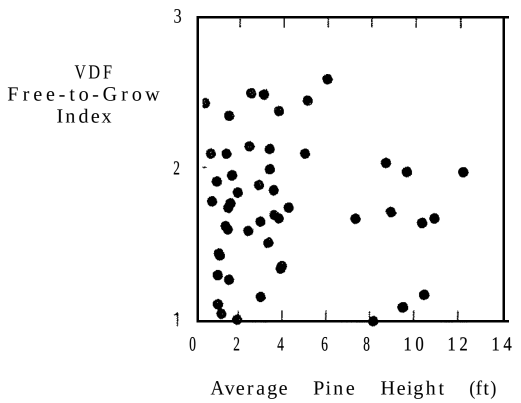

Figure 3. Initial VDF Free-to-grow Index vs. average pine height for current RL-4I locations.

Analysis

The adequacy of coverage across hardwood density and pine age classes is of particular concern since the majority of sites have been established. Figure 2 is a plot of hardwood rootstock/ac vs. average pine height at the time of establishment for the current locations. Average pine height is used because it incorporates both stand age and site quality. Generally, there is a wide range of hardwood densities represented for stands of different pine heights. There are two noticeable trends, the very high rootstock densities present for average pine height less than 2 ft, and the lack of data points in the 5-7-ft average pine height range. There is no causal relationship implied by Figure 2. The lack of extremely high hardwood densities in older stands may be due to: (1) age related differences in the judgment of what constitutes a separate hardwood rootstock; (2) rapid natural thinning of hardwood rootstocks under high competition levels; (3) rapid loss of pine stocking under high hardwood densities so that older stands could not meet the minimum pine stocking requirements; or to (4) the avoidance of older stands with these high competition levels due to the difficulty of establishing and measuring plots.

An alternative method of judging coverage is to use a measure of competition other than hardwood density. The crop-centered Virginia Division of Forestry free-to-grow index (Zutter et al., 1985) is plotted against average pine height in Figure 3. The free-to-grow index in Figure 3 is the average of the pine ratings for a location, and can range between one and four. A rating of one suggests that all pines are free to grow, while a rating of four would suggest that fewer than 10 percent will make it to rotation. This index incorporates hardwood density, hardwood size and distribution, and pine vigor without direct measurements of the hardwoods. Generally, the coverage of the free-to-grow index appears to be very good.

The purpose of this study is to describe the effects of competing hardwood and herbaceous vegetation on pine survival, growth and yield, not to develop a comprehensive growth projection system. Relationships and models derived from this study should be suitable to modify, adjust, or include in existing and developed yield models. The primary analysis will be investigation of pine-competing vegetation growth relationships, and development of models of these relationships using regression techniques. Single and multidimensional response surface variables as **a** function of hardwood and/or herbaceous variables will be developed using appropriate mathematical models.

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SPECIES-AREA RELATIONSHIPS FOR THE ARBORESCENT COMPONENT OF THE OAK-PINE TYPE [1]

James W. McMinn and William D. Pepper [2]

Abstract. Silvicultural enhancement of woody species richness is often implied in increasing demands for recreation, wildlife habitat, and maintenance of biological diversity. Within a forest type the estimated species richness increases with increasing sample area before becoming relatively stable. This relationship was examined by analyzing increasingly large aggregates of 40-m^2 quadrats in the oak-pine type. If species richness is to be analyzed as a response variable in this and similar types, experimental units must be at least 0.1 ha in size and subsamples must be well dispersed.

Introduction

Southern silviculturists are increasingly concerned with species mixtures. Reasons for this include: (1) increased recreational use of forestlands by publics that object to monocultures; (2) habitat requirements of both consumptive and nonconsumptive wildlife species; and (3) the global concern for maintenance of biological diversity. A related and widely held view is that complex mixtures of many species are inherently desirable. These issues generally imply a desire to enhance woody-species richness by means of silvicultural practices. Because scientists must develop information that can guide management's response to the issues, these developments have implications for research. It is apparent that samples in mixed stands must be larger than samples in stands composed of single species, but just how large should experimental units or samples be? As sample area increases there will be an increase in the number of species encountered+ but within a given forest type the relationship will tend to level off at some point. Ecologists have studied the nature of species-area relationships at least since the 1920's (Gleason 1922, Arrhenius 1923). A commonly-used analytical tool has been the species-area curve, which is a plot of the number of species sampled as a function of the area sampled (Palmer 1990). Species-area curves for a range of conditions created in the oak-pine type were used to develop the guidelines presented here.

Methods

The stands from which data were collected represented four different conditions that could affect species richness and spatial distribution. The study area was in Dawson County in the Upper Piedmont of Georgia. Initially, mean basal area was 21 m^2ha^{-1}. Of this, about 27 percent was in pines; 27 percent in red oaks; 21 percent in white, post, or chestnut oak; 9 percent in other

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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hard hardwoods (primarily hickories); 3 percent in soft hardwoods; 1 percent in shrubs, and 11 percent in what USDA Forest Service Forest Survey classifies as miscellaneous species. Species and species groups recognized in this study are presented in Table 1. Ten years prior to these observations the stands were whole-tree harvested in the dormant season and early growing season to 2.5- and 10-cm lower diameter limits, then allowed to regenerate spontaneously. The four combinations of season and diameter limit were replicated in a completely randomized design. A detailed description of the study area and procedures was given by McMinn and Nutter (1988). The four harvesting treatments resulted in 9-year-old stands with different proportions of hardwoods of coppice origin, pines of seedling origin, and harvest residuals of both species groups. All treatments resulted in at least some hardwood coppice growth, which was virtually the only source of regeneration following 2.5-cm-limit harvests during the growing season. The growing-season, lo-cm-limit stands also included residual stems, but almost no pines of seedling origin. The dormant-season, 2.5-cm-limit areas were occupied by pines of seedling origin and hardwood coppice. Stands that developed following dormant-season, lo-cm-limit harvests included substantial proportions of all three components.

Nine 40-m² circular quadrats were established in a square grid in each treatment plot. Quadrats were on 11.3-m centers, and outside grid limits were approximately 30 x 30 m. All stems larger than 1 cm dbh were recorded by species or species group and quadrat on all treatment plots that included the full set of nine quadrats. In our experience, the 40-m² circular quadrat is the largest practical sampling unit for such observations.

Analysis of variance and coefficients of variation were employed to examine effects of the treatments on species richness and spatial distribution. Species-area curves were then generated by aggregating quadrats in different sequences to address questions about effects of the number and arrangement of sampling units. Species-area curves can be generated from nested quadrats of increasing size or sequentially added quadrats of equal size. Palmer (1988, 1990) recognized that species-area curves ".. . will increase more rapidly with sequential additions than with nested quadrats, because nested quadrats sample nearby areas before distant areas, and species composition is generally more similar in nearby areas than in distant areas. " It follows that within a treatment area or plant community, species-area curves generated by sequential additions of widely-dispersed quadrats should increase more rapidly than those generated by sequential additions of nearby quadrats. Five sequences were employed, the four shown in Figure 1 and a random ordering for each treatment plot. Themaximum clustered sequence begins in the center of an area and adds quadrats as close as possible to the first one in all directions. The increasing area sequence begins in one corner and adds the closest quadrats, but in only two directions, so that successive samples are forced farther away from the first one earlier. The perimeter sequence produces a more dispersed sample earlier by covering the perimeter of an area completely before adding the final quadrat in the center. The dispersed sequence adds each quadrat by selecting a location most distant from the prior sample.

Table 1. Taxonomic categories by USDA Forest Service Forest Inventory and Analysis code.

FIA code	Common name	Scientific name
008	Azalea	*Rhododendron calendulaceum* (Michx.) Torr.
038	Hawthorn	*Crataegus* spp.
058	sumac	Rhus spp.
077	Other shrubs	--
110	Shortleaf pine	*Pinus echinata* Mill.
131	Loblolly pine	*Pinus taeda* L.
132	Virginia pine	*Pinus virginiana* Mill.
316	Red maple	*Acer rubrum* L.
400	Hickory	*Carya* spp.
491	Dogwood	*Cornus florida* L.
521	Persimmon	*Diospyros virginiana* L.
621	Yellow-poplar	*Liriodendron tulipifera* L.
693	Blackgum	*Nyssa sylvatica* Marsh.
711	Sourwood	*Oxydendrum arboreum* (L.) DC.
762	Black cherry	*Prunus serotina* Ehrh.
802	White oak	*Quercus alba* L.
806	Scarlet oak	*Quercus coccinea* Muenchh.
812	Southern red oak	*Quercus falcata* Michx.
824	Blackjack oak	*Quercus marilandica* Muenchh.
832	Chestnut oak	*Quercus prinus* L.
835	Post oak	*Quercus stellata* Wangenh.
837	Black oak	*Quercus velutina* Lam.
931	Sassafras	*Sassafras albidum* (Nutt.) Nees
390	Other trees	--

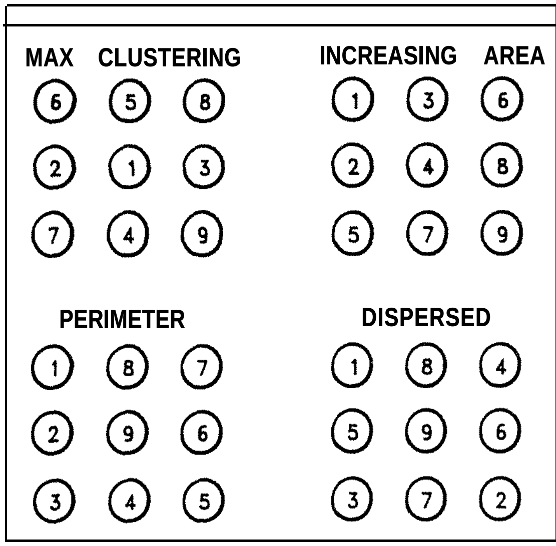

Figure 1. Sequences in which quadrats were aggregated to explore the nature of the species-area relationship.

Results and Discussion

Species richness was not affected by harvesting treatments, although the seasonal effect approached significance (Table 2)--a result of seedling-origin pines following dormant-season, but not growing-season, harvests. The differences in variability by treatment in the number of species encountered on individual 40-m² quadrats indicate a substantial effect of the treatment combinations on the spatial pattern or clustering of species in the mixtures (Table 3). The foregoing suggests that the treatments may

Table 2. Analysis of variance for woody species richness in spontaneously-regenerated stands by season and diameter limit of whole-tree harvesting.

Source of variation	df	Mean square	F	P > F
Season (S)	1	10.4167	4.75	0.0722
Limit (L)	1	4.8167	2.19	0.1890
SXL	1	0.4167	0.19	0.6783
Error	6	2.1944		

Table 3. Descriptive statistics for number of woody species encountered on 40-m^2 quadrats 10 years after four harvesting treatments.

Harvest				
Season	Limit	Mean	Standard deviation	Coefficient of variation
	-cm-	--number of species--		
Dormant	2.5	8.72	1.9689	0.23
Dormant	10	7.59	2.2405	0.30
Growing	2.5	6.41	2.1884	0.34
Growing	10	6.85	1.2551	0.18

be expected to exhibit large-enough differences in species-area relationships to preclude pooling data across treatments.

Figure 2 presents mean species-area relationships for selected quadrat sequences by treatment. In the lower range of number of quadrats the dispersed sequence did produce a more rapid increase than the clustered sequence for all treatments. Generally, over the complete range, the clustered sequence tends to be linear and the dispersed sequence to be parabolic. As would be expected, the random sequences produced varied patterns of means, but reached the maximum number of species as soon as or sooner than the clustered sequence in all cases.

Tables 4 through 7 present the species-area relationships for all sequences and treatments as percent of total species encountered by quadrat number in the sequence. Generally, those sequences intermediate between the most dispersed and most clustered fell between those two sequences in number of species encountered by a given quadrat. Note that in three out of four treatments the maximum number of species was encountered prior to the last quadrat in at least one out of the five sequences, but in one treatment the maximum number was not encountered prior to the last quadrat in any sequence. This suggests that we are getting close, but are perhaps not sampling a large enough area to estimate species richness in this mixed

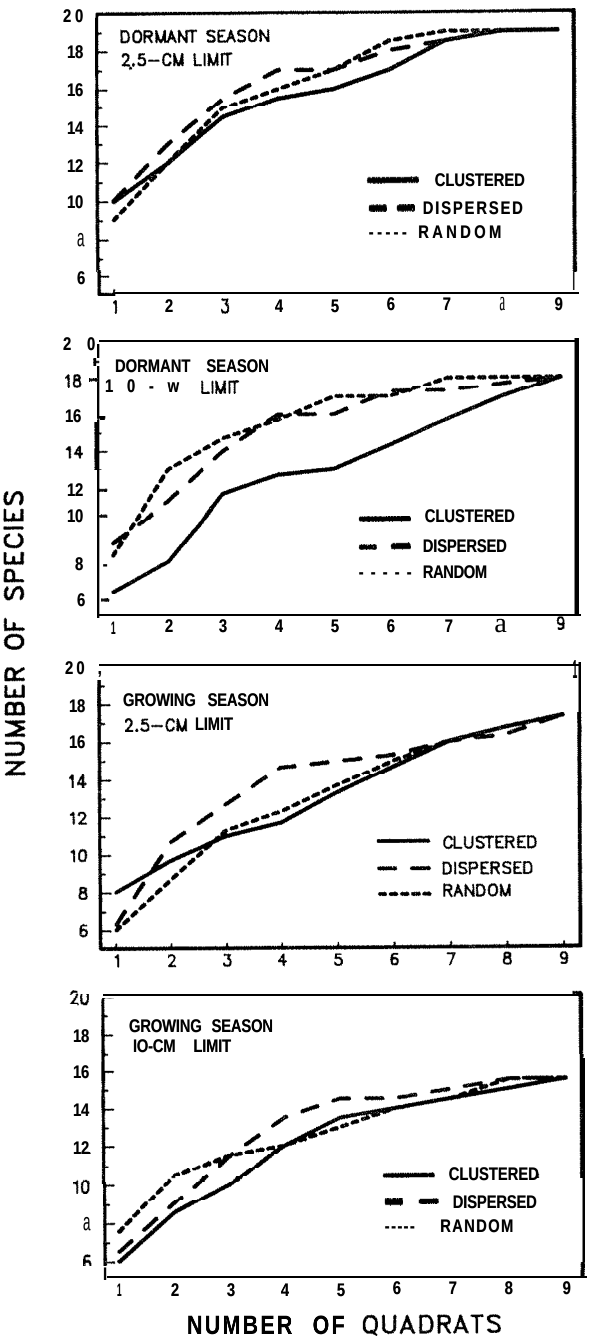

Figure 2. Relationship of number of species encountered to number of quadrats observed for three sequences of aggregation following four harvesting treatments.

type. The outer limits of our quadrats in the square grids spanned 29.73 m, or an area of 0.088 ha. It is our recommendation that estimates of species richness in this and similar forest types be based on areas of at least 0.1 ha.

The specific sequences were employed to generate information about the nature of species-area relationships and to infer sampling strategies for species richness in the type studied. The information has some clear implications for different sampling situations. When the number of quadrats is fixed, and particularly when the total area sampled may be marginal, the quadrats should be located for maximum dispersal over the area with priority given to the outer periphery. Frequently, the objective will. require only some general index of species richness among treatments or vegetation types, rather than accounting for virtually all extant species. In such a case it becomes more critical to employ a dispersed pattern with enough quadrats to approach the inflection point on the parabolic curve, i.e., a point of diminishing returns in number of species per additional quadrats. The shape of the species-area curve is very significant, because the more strongly parabolic, the better the index of richness among types or treatments with incomplete sampling.

Table 4. Mean number of species encountered, expressed as a percentage of total species encountered, by quadrat sequence and number on dormant-season, 2.5-cm-limit areas.

Quadrat number	Quadrat sequence				
	Maximum clustering	Increasing area	Perimeter	Maximum dispersal	Random
	(percent)				
1	52.6	52.6	52.6	52.6	47.4
2	63.2	60.5	60.5	68.4	63.2
3	76.3	68.4	73.7	81.6	78.9
4	81.6	81.6	84.2	89.5	84.2
5	84.2	89.5	89.5	89.5	89.5
6	89.5	94.7	94.7	94.7	97.4
7	97.4	97.4	97.4	97.4	100.0
8	100.0	100.0	100.0	100.0	100.0
9	100.0	100.0	100.0	100.0	100.0

Table 5. Mean number of species encountered, expressed as a percentage of total species encountered, by quadrat sequence and number on dormant-season, 10-cm limit areas.

Quadrat number	Quadrat sequence				
	Maximum clustering	Increasing area	Perimeter	Maximum dispersal	Random
	(percent)				
1	35.2	50.0	50.0	50.0	46.3
2	44.4	59.3	59.3	62.9	72.2
3	64.8	66.7	70.4	77.8	81.5
4	70.4	68.5	75.9	88.9	87.1
5	72.2	77.8	83.3	88.9	94.4
6	79.6	87.1	88.9	96.3	94.4
7	87.1	88.9	96.3	96.3	100.0
8	94.4	94.4	98.2	98.2	100.0
9	100.0	100.0	100.0	100.0	100.0

Table 6. Mean number of species encountered, expressed as a percentage of total species encountered, by quadrat sequence and number on growing-season, 2.5-cm areas.

Quadrat number	Quadrat sequence: Maximum clustering	Increasing area	Perimeter	Maximum dispersal	Random
	(percent)				
1	46.2	36.5	36.5	36.5	34.6
2	55.8	50.0	50.0	61.6	50.0
3	63.5	65.4	63.5	73.1	65.4
4	67.3	78.9	76.9	84.7	71.1
5	76.9	86.6	84.6	86.6	78.9
6	84.7	90.4	86.6	88.5	86.6
7	92.3	96.2	92.3	92.3	92.3
8	96.2	96.2	94.2	94.2	96.2
9	100.0	100.0	100.0	100.0	100.0

Table 7. Mean number of species encountered, expressed as a percentage of total. species encountered, by quadrat sequence and number on growing-season, 10-cm areas

Quadrat number	Quadrat sequence: Maximum clustering	Increasing area	Perimeter	Maximum dispersal	Random
	(percent)				
1	38.7	41.9	41.9	41.9	48.4
2	54.8	61.3	61.3	58.1	67.7
3	64.5	77.4	74.2	74.2	74.2
4	77.4	80.6	80.6	87.1	77.4
5	87.1	87.1	90.3	93.5	83.9
6	90.3	90.3	90.3	93.5	90.3
7	93.5	93.5	96.8	96.8	93.5
8	96.8	96.8	100.0	100.0	100.0
9	100.0	100.0	100.0	100.0	100.0

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EFFECTS OF A SINGLE CHEMICAL TREATMENT ON LONG-TERM HARDWOOD DEVELOPMENT IN A YOUNG PINE STAND[1]

William D. Boyer [2]

Abstract. The long-term effect of a single chemical treatment for control of understory hardwoods in pine stands has been followed for 16 years. The study began in 1973, when 12 treatments were established in stands of 14-year-old longleaf pine (*Pinus palustris* Mill.) in southwest Alabama. Four burning treatments, namely biennial burns in winter, spring, and summer plus an unburned check, were each combined with three understory hardwood control treatments: chemical injection of all hardwoods; repeated clearing of woody stems; and no treatment. After 16 years, the chemical treatment combined with fire has not allowed any hardwoods to reach sizes greater than 0.5 inch dbh. Even without fire, hardwood midstory (> 1.5 inches dbh) development after chemical treatment was slow. After 16 years, the hardwood midstory on unburned chemical plots consisted of 47 stems and 1.0 ft^2 basal area/ac, while on unburned check plots there were 340 stems and 15.5 ft^2 basal area/ac. Over the 16 years of observation, seedlings and sprouts (0.5 inch dbh or less) of hardwood tree species on chemical plots declined, from 5,400 pretreatment to 3,800 stems/ac. These stems on plots without chemical treatment rose from 5,200 to 9,500/ac.

Introduction

Controlling understory hardwoods within young pine stands is expected to provide a number of benefits, including improved growth of overstory pine, reduced fuel loads, easier access, reduced cost of future site or seedbed preparation, and increased grass and other herbaceous cover. Little information is presently available on the long-term effects of herbicide treatments on controlling hardwoods, and especially on slowing future hardwood development.

The effects of chemical eradication of understory hardwoods in a mature loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine stand were still apparent 23 years later when hardwood basal area was about 6 ft^2/ac in treated stands compared with 36 ft^2/ac in untreated stands (Cain 1985). This difference had not affected the volume growth of overstory pine.

Hardwoods in a 7-year-old loblolly pine plantation averaged 4 ft^2 basal area/ac when a single herbicide treatment was applied to all hardwood stems. Ten years later, hardwood regrowth averaged 0.6 ft^2 basal area/ac. Without treatment, hardwoods had increased to 41.4 ft^2 basal area/ac (Clason 1984). Hard-

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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wood control improved the volume growth of these young pine stands, as volume in untreated stands was 30 percent below that in treated stands.

In another study, 11 years of annual chemical and/or mechanical eradication of understory hardwoods in a selectively managed loblolly/shortleaf pine stand failed to have an extended impact on understory hardwoods. Eighteen years after treatments stopped there were as many hardwoods present--about 3500 stems/ac--as there were before eradication efforts began (Cain and Yaussy 1984). Sixty-five percent of these hardwood stems were seedlings; the remainder were saplings. However, there was no comparative information on hardwood development in the absence of any eradication treatments.

A study was initiated in 1973 to determine the effects of several understory hardwood control treatments, including combinations of fire, mechanical, and chemical methods, on understory succession and overstory growth in natural stands of longleaf pine (P. palustris Mill.). Effects of treatments on overstory pine growth for the first 10 years of observation have been reported (Boyer 1987). This report is on 16 years of woody understory response to a single chemical hardwood control treatment, both with and without biennial prescribed burning treatments.

Methods

The study was established in 1973 on a sandy upland coastal plain site on the Escambia Experimental Forest[1] in southwest Alabama. Study areas supported well-stocked natural stands of longleaf pine averaging about 700 trees/ac. These stands were 14 years old from seed, 12 years from time of release from the parent overstory.

Three blocks were established, each with twelve 0.4-ac square plots. All plots were thinned to an average 503 dominant-codominant trees/ac. Residual pines in square O.l-ac net plots were marked and numbered, and total height and dbh recorded. Pines averaged 22 ft in height, 3.2 inches in dbh, and 30 ft^2 basal area/ac. Average age 50 site index (Farrar 1981) on study blocks, based on dominant-codominant tree heights at age 30, ranged from 74 to 78 ft.

Woody competition before treatment was estimated by counts of all woody stems on nine 3.1-ft^2 sample plots systematically located in each net plot. Hardwood basal area (at breast height), estimated for each net plot with a lo-factor wedge prism, averaged 3.6 ft^2/ac. The estimate for all small stems (< 1.5 inches dbh) of hardwood tree species, based on sample-plot counts, was 5,300/ac. Eighty-six percent were oaks (Quercus sp.), 11 percent dogwood (Cornus florida L.), and the remainder persimmon (Diospyros virginiana L.) and sassafras [Sassafras albidum (Nutt.) Nees]. Woody vegetation other than tree species averaged 102,000 stems/ac, with gallberry

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[1] Maintained by the Southern Forest Experiment Station, U.S. Department of Agriculture, in cooperation with the T.R. Miller Mill Co., Brewton, AL.

[*Ilex glabra* (L.) Gray], blueberries and huckleberries (*Vaccinium* sp., *Gaylussacia* sp.), and blackberries (*Rubus* sp.) making up 91 percent of the total. Vines, rooted in sample plots, averaged 14,400 stems/ac, the majority (72 percent) being honeysuckles (*Lonicera* sp.), and the balance greenbriars (*Smilax* sp.).

Twelve treatment combinations were randomly assigned among the 12 plots in each block. Four fire treatments were performed, namely, prescribed fire at 2-year intervals in winter (January-February), spring (April-May), and summer (July-August) plus an unburned check. Each of the four fire treatments was combined with three supplemental treatments as follows: (1) inject all woody stems down to about l-inch groundline diameter with undiluted 2,4-D amine in the spring of 1973; (2) hand clear, by cutting just above groundline, all woody stems more than 4.5-f t tall in the spring of 1973 and at 2-year intervals thereafter, as needed; and (3) leave untreated.

The last fire on all study areas had been a prescribed burn in January 1962. Because of heavy fuel accumulations in the sapling pine stands, all three seasons of burn treatments were initiated with a cool winter prescribed fire in January 1974.

Plots were first reexamined in the winter of 1980, after seven growing seasons. At this time, all net-plot hardwoods in the 2-inch and larger dbh classes (> 1.5 inches dbh) were inventoried by species, and the dbh was recorded. In the fall of 1980 smaller woody vegetation was again sampled on the nine subplots within each net plot. The number of stems, by species, was recorded in two groups: those less than and those above 0.5 inch in diameter at 6 inches above groundline, up to 1.5 inches in dbh. All plots were similarly remeasured in the fall and winter of 1982-1983, 1985-1986, and 1988-1989. During the last two remeasurements, all hardwoods in the 1-inch dbh class were included in the entire net-plot inventory and dropped from the subplot count, which then included only woody stems 0.5 inches or less in dbh.

Results

Hardwood Midstory

Development of midstory hardwoods (> 1.5 inches dbh) was allowed to proceed on all treatments except the mechanical, where repeated handclearing kept all stems small. Three hardwoods (2.0-2.7 inches dbh) surviving the chemical treatment were still present on summer burn plots in 1980, but only one remained in subsequent examinations. The density of the dominant pine overstory increased from an average 30 ft^2 basal area/ac in 1973 to 97 ft^2/ac in 1989.

Hardwood ingrowth on chemically treated plots has been entirely excluded by all prescribed fire treatments. Even without burning, there was no hardwood ingrowth during the first 10 years after chemical treatment. Sixteen years after treatment there were only 47 stems and 1.0 ft^2 basal area/ac on unburned chemical plots (Table 1). Of these, tree species made up 30 stems and arborescent shrubs 17. All of the stems were in the Z-inch dbh class.

Considering only plots without chemical or mechanical hardwood control treatments from 1980 to 1989, the density and numbers of midstory hardwoods increased on both unburned and winter-burned plots and declined on spring- and summer-burned plots (Table 1). By 1989 there were 220 stems and 10.4 ft^2 basal area/ac on winter-burned plots; 340 stems and 15.5 ft^2 basal area/ac on unburned plots.

Table 1. Effect of fire and chemical treatment on midstory hardwoods (> 1.5 inches in dbh).

Treatments	Year 1980	1983	1986	1989
	(stems/ac)			
Winter burn				
Chemical	0	0	0	0
None	190	237	223	220
Spring burn				
Chemical	0	0	0	0
None	153	113	50	7
Summerburn				
Chemical	10	3	3	3
None	90	97	77	43
No burn				
Chemical	0	0	30	47
None	287	307	317	340

Midstory Threshold

The immediate source for recruitment into the midstory is woody vegetation in the l-inch dbh class (0.6-l .5 inches in dbh) . This class was tallied on entire net plots in both 1986 and 1989 (Table 2). As with larger stems, the chemical treatment plus burning have prevented any recruitment into the l-inch dbh class. Without chemical treatment, only the spring burn prevented any recruitment into this size class. In the absence of fire, however, woody stems in the l-inch dbh class on chemical plots approached the number on untreated plots in 1986 and exceeded the number on untreated plots in 1989. Woody stems in this size class actually declined on untreated plots between 1986 and 1989, possibly because of competition from an already well-established hardwood midstory that does not yet exist on chemical plots.

A species breakdown of woody stems in the 1 inch d. b. h. class in 1989 revealed that, on unburned chemical plots , only 36 percent of the stems were tree species, while 64 percent were arborescent shrubs (Table 3). The reverse occurred on unburned check plots, where 80 percent of the stems were tree species and only 20 percent were arborescent shrubs.

Table 2. Effect of fire and chemical treatments on woody stems in the l-inch dbh class.

Year	Treatment	Season of burn				Average
		Winter	Spring	Summer	No burn	
		(stems/ac)				
1986	Chemical	0	0	0	220	55
	None	140	0	60	317	129
1989	Chemical	0	0	0	343	86
	None	63	0	10	270	86

Table 3. Effect of fire and chemical treatments on hardwood trees and shrubs in the l-inch dbh class in 1989.

Treatment	Season of burn				Average
	Winter	Spring	Summer	No burn	
	(stems/ac)				
	Tree Species				
Chemical	0	0	0	123	31
None	63	0	10	217	73
	Arborescent Shrubs				
Chemical	0	0	0	220	55
None	0	0	0	53	13

The impact of the chemical treatment is still apparent after 16 years., with fewer tree species than shrubs in the l-inch dbh class. Without chemical treatment, this size class is dominated by tree species. Shrubs in the l-inch dbh class were found only on unburned plots.

Hardwood Regeneration

All woody stems below the l-inch dbh class were tallied on sample plots to obtain an estimate of the number of stems by species or species groups.

These comparisons include all three supplemental treatments, because the mechanical treatment only kept plants small and did not eliminate them, Tree species composed only a fraction of the total woody stems on the forest floor. Over the five examinations, from establishment to 1989, the average number of tree stems on all study plots ranged from 5,300 to 12,900/ac. At the same time, shrubs and other woody vegetation (excluding vines) ranged from 58,000 to 208,000 stems/ac.

Tree species. Hardwood tree regeneration was consistently less on chemical plots than on all other plots (Fig. 1). So far, none of the burning treatments have affected regeneration. Plots assigned to the chemical treatment initially averaged 5,400 compared with 5,200 stems/ac for all other plots. After treatment, the difference reached a peak in 1983, when chemical plots averaged 4,100 and all others averaged 17,400 s tems/ac. By 1989, chemical plots averaged 3,800 while all other plots had 9,500 stems/ac. The decline in the number of stems after 1983 may be due in part to increasing density of the pine overstory and to several growing seasons that were drier than normal. The 1986 examination occurred at the end of a growing season with both spring and summer fires. Odd year examinations followed a full growing season without fire.

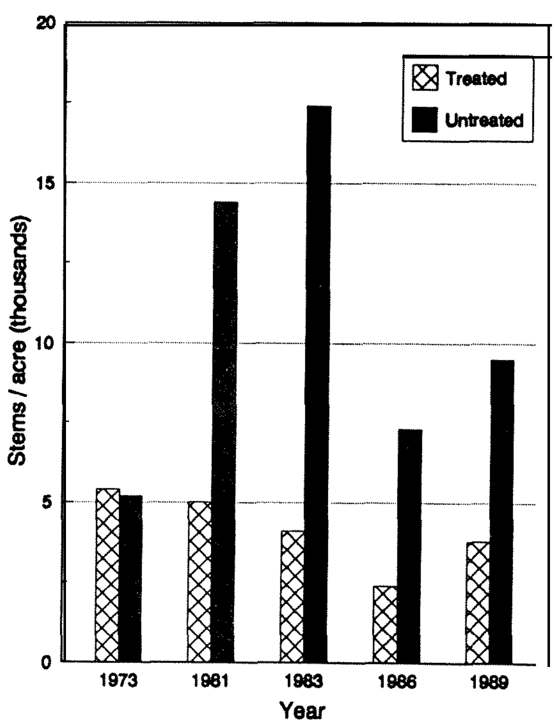

Figure 1. Hardwood tree regeneration (< 0.6 inch dbh) on plots with and without chemical treatment.

Data for the 1981 and 1983 examinations include as regeneration all stems 1.5 inches or less in dbh, while data for the 1986 and 1989 examinations include only stems 0.5 inch or less in dbh. However, numbers in the l-inch dbh class, averaging less than 100/ac by 1989 (Table 3), were too few to affect values given for regeneration in 1981 and 1983.

Sixty-three percent of the hardwood tree regeneration on chemical plots was composed of three species of oak, primarily post oak (Q. stellata Wangenh.). Dogwood accounted for 25 percent, and three other species for 12 percent of the regeneration. Five oak species made up 75 percent, and dogwood composed 19 percent of the regeneration on all plots without the chemical treatment.

Non-tree species. By far the largest number of woody stems on the forest floor were not tree species but shrubs, vines, and other perennial woody vegetation.

The chemical treatment has not significantly (0.05 level) affected numbers of stems of this woody vegetation in any of the four remeasurements since the study began.

Woody vegetation (excluding vines) amounted to 102,000 stems/ac in 1973 and 112,000 stems/ac in 1989. In 1989, chemical plots averaged 123,000 stems/ac and all other plots averaged 106,000 stems/ac.

Vines averaged 21,000 stems/ac in 1989. Overall, yellow jessamine [Gelsemium sempervirens (L.) Ait. f.], greenbriar, and honeysuckle made up 92 percent of all vines (the latter found only on unburned plots).

Discussion And Conclusions

The results of this study indicate that a single chemical injection treatment of hardwoods in a young pine stand on a coastal plain site, both with and without periodic prescribed fire, may have a major impact on subsequent long-term development and structure of understory hardwoods. The treatment has resulted, even after 16 years, in sharp reductions in the numbers of stems of hardwood tree species in all size classes, from midstory to regeneration on the forest floor.

Chemical treatment of hardwood tree stems in a pine stand, followed by periodic prescribed fire at any season, can prevent hardwood encroachment into the midstory. In the study reported here, the chemical treatment combined with biennial prescribed fires has entirely prevented hardwood ingrowth into size classes greater than 0.5 inch in dbh.

Even in the absence of fire, hardwood midstory development after chemical treatment is slow. For the first 10 years no hardwoods grew into the midstory (> 1.5 inches dbh). Even after 16 years there were only 47 midstory stems/ac, none of which exceeded 2.5 inches in dbh. All stems of this size are susceptible to top-kill by a prescribed fire and are likely to remain so for several years.

In the absence of fire, chemical treatment favors development of arborescent shrubs in lieu of tree species. Since the chemical treatment was confined largely to tree species, a source for both seeds and sprouts had been reduced, and the growing space occupied by other woody vegetation. Over one-third of the midstory stems (> 1.5 inches in dbh) were arborescent shrubs and nearly two-thirds of the stems in the l-inch dbh class were shrubs. However, 80 to 98 percent of all woody stems over 0.5 inch dbh on unburned plots without chemical or mechanical treatment were tree species rather than shrubs.

A single chemical treatment also has a long-term effect on hardwood tree regeneration ($\leq$ 0.5 inch dbh) on the forest floor. Although this regeneration on chemical plots averaged 3,800 stems/ac, compared to 9,500 stems/ac on all other plots, this relatively small number still represents a continuing source of potential recruitment into the midstory whenever conditions become favorable.

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GROWTH OF PINE-HARDWOOD MIXTURES ON TWO UPLAND SITES IN THE. GEORGIA PIEDMONT: INITIAL CROWN AREA RELATIONSHIPS[1]

Klaus Steinbeck, Phillip M. Dougherty and Judith A. Fitzgerald[2]

Abstract. Two upland hardwood stands with a history of high-grading were inventoried prior to logging and then clearcut to a 2-inch dbh limit in the winter of 1982 and 1983. Both sites were hand-planted with 1-O loblolly pine (*Pinus taeda* L.) seedlings at a spacing of 8x10 ft. The cross sectional crown areas of 15 pines on each site and all competing hardwoods within 6.56 f t of the pines were determined. After two and three growing seasons, 85 percent of the pines had survived and were maintaining themselves well in the mixture. Red oaks, hickories, and black cherry of sprout origin, and yellow poplar seedlings dominated the hardwood regeneration. Crown area development for both hardwoods and loblolly pine will be presented.

Introduction

Many upland stands in Georgia have a history of partial cutting of pine without provision for pine regeneration. Hardwoods naturally have become dominant on such sites. Consequently, the oak-hickory type has expanded by about 24,000 ac annually in Georgia between 1982 and 1989 (Thompson 1989). Most of these upland sites are neither fertile nor wet enough to rapidly produce high quality hardwood timber. Higher timber yields would be obtained by converting these stands to loblolly pine (*P. taeda* L.). Many of these low-grade hardwood stands are owned by individuals who either cannot afford to or are unwilling to invest money in intensive site preparation to convert these stands to pine. This study was begun in 1982 with the objective of finding inexpensive means with which nonindustrial, private landowners might convert upland sites which now support scrub hardwood stands to quality pine-hardwood stands. The results reported here deal with the development of both hardwood regeneration and interplanted pine following clearcutting.

Methods

Two upland Piedmont sites supporting poor quality hardwood stands located in Jackson County, Georgia, were used as study sites. Soils on both sites are classified as an eroded Madison series. This soil is estimated to have a site index (base age 50) for loblolly pine of 75 ft. Site 1 and Site 2 contained 8 and 6 ac, respectively.

The vegetation before logging was inventoried on five randomly located, O.l-ac plots at each site in autumn 1982. Vegetation was subdivided into three strata: overstory

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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(trees > 16.4 ft); shrubs (3.3-16.3 ft); and groundcover (groundline to 3.2-ft tall). Total number of stems per plot and stratum were tallied for each species. For the trees, basal area was also measured.

Site 1 was logged between December 1982 and January 1983. Site 2 was logged the following winter. Logging entailed cutting all stems with ≥ 2-inch dbh using chainsaws. The following spring after logging, sites were dibble planted with 1-0, bare-rooted loblolly pine seedlings at an 8x10-ft spacing.

The regeneration on each site was first assessed 2 years after clear-cutting on Site 1 and 3 years after cutting on Site 2. All woody vegetation > 1.64 ft centered on plots within a 6.56-ft radius of the planted pines were assessed on 15 plots at each site (Wagner 1982). In order to be able to remeasure the same plants each year, a 6.56-ft-long rod was rotated clockwise around the central pine. Plants were measured in the order encountered. The distance to the pine for each hardwood was also recorded to resolve instances where several individuals of the same species were located on the same radial line. This system readily allowed reidentification of individual plants as well as identifying those which disappeared or appeared between measurement dates.

The following measurements were recorded for the pine and each woody competitor on every plot: Species, origin (seedling or sprout), height of the tallest stem, the narrowest and widest crown diameter of a clump, average height at which crown diameters were measured, and distance from the pine.

Results

Preharvest Inventory

Both sites were occupied by unevenaged hardwood stands, with some trees more than 100 years old. Even- though the sites were a few miles apart, the stands occupying them were quite similar. Both were well stocked with 90 and 72 ft^2 of basal area/ac (Table 1). A total of 17 genera was found in the overstory which was dominated by white and red oaks (ex. Quercus alba L. and Q. falcata Michx). Hickories (Carya spp.), shortleaf pine (P. echinata Mill), and dogwood (Cornus florida L.) were other major components.

These statistics may conjure up an image of a vigorous, pole-sized stand of oaks and hickory, which would be false. Many of the trees were of poor vigor; some of them overmature wolf trees. As already stated, these sites are too infertile to rapidly grow quality hardwoods. There were no sweetgum (Liquidambar styraciflua L.) trees in the overstory or at groundlevel at Site 1. However, sweetgum was present in all strata at Site 2. There were an average of 34 sweetgum saplings/ac in the overstory stratum on Site 2. Species with < 1 ft^2 of basal area/ac were lumped together in the miscellaneous category (Table 1) which contained a few black cherry (Prunus serotina Ehrh.), blackgum (Nyssa sylvatica Marsh), winged elm (Ulmus alata Michx), eastern red cedar (Juniperus virginiana L.), and persimmon (Diospyros virginiana L.) trees.

Table 1. **Preharvest inventory of the overstory (>16.4 ft)**

Species	Site 1		Site 2	
	Basal area	Density	Basal area	Density
	ft^2	stems/ac	ft^2	stems/ac
Quercus spp. (white)	29.4	135	26.8	74
Quercus spp. (red)	24.6	76	23.6	72
Carya spp.	13.9	143	5.5	90
Pinus echinata	13.4	28	1.0	2
Cornus florida	3.5	84	1.5	26
Liriodendron tulip.	2.2	30	5.1	24
Liquidambar styrac.	0	0	4.9	34
Nyssa sylvatica	1.5	24	0	0
Oxydendrum arboreum	1.2	16	1.6	8
Miscellaneous	0.3	7	2.5	20
Totals	90.0	543	72.5	350

A total of 24 genera were represented in the shrub-sized stratum of both sites (Table 2). Hickories were the most numerous component, followed closely by yellow poplar (Liriodendron tulipifera L.) and black cherry saplings. Of special interest is the advance regeneration of oaks. An average of >150 red oak and nearly 50 white oak saplings grew on both sites. The shrub layer at Site 2 contained more stems and more species than that of Site 1. Shade intolerant species such as yellow poplar and black cherry were more prevalent, probably indicating recent cutting in the overstory. Species with < 10 stems/ac are reported in the "miscellaneous" category, which contained red maple (Acer rubrum L.) at Site 1, and sourwood (Oxydendrum arboreum L.), holly (Ilex opaca Ait.), red mulberry (Morus rubra L.), and poison ivy (Toxicodendron radicans L.) at Site 2.

Site 2 supported a much denser ground layer of vegetation, 40,000 vs. 15,000 plants/ac, than Site 1 (Table 3). The same fraction, about one-fifth, was arborescent species at both sites. Twenty-six genera, although not the same, were represented at each site. As in the shrub layer on Site 2, there was also a better representation of less-tolerant species at groundlevel. Blueberries (Vaccinium spp.) and grape vines (Vitis spp.) predominated everywhere, although honeysuckle (Lonicera japonica Thunb.) was sparse and sweetgum absent on Site 1. Several thousand white and red oak stems were present in the preharvest understories. Their age, unfortunately, was not determined. However, there was no evidence of recent fire or cattle grazing in the stand. Therefore, they presumably were of recent origin rather than being repeatedly killed back and resprouting.

Table 2. Preharvest inventory of the shrub stratum (3.3-16.3 ft)

Species	Site 1	Site 2
	------ Stems/ac ------	
Carya spp.	263	212
Prunus serotina	35	240
Liriodendron tulipifera	58	230
Quercus spp. (red)	188	130
Cornus florida	98	160
Nyssa sylvatica	118	36
Crataegus spp.	10	104
Calycanthus floridus	0	74
Liquidambar styraciflua	13	60
Quercus spp. (white)	40	56
Vaccinium arboreum	53	22
Diospyros virginiana	0	46
Ulmus alata	0	36
Oxydendrum arboreum	28	6
Celtis laevigata	0	24
Callicarpa americana	0	20
Sassafras albidum	10	18
Aralia spinosa	10	0
Eleagnus sp.	0	10
Pinus taeda	8	2
Miscellaneous	3	8
Totals	935	1494

Table 3. Preharvest inventory of the groundcover (Q-3.2 ft)

Species	Site 1	Site 2
	------- plants/ac -------	
Vaccinium spp.	4790	8094
Vitis rotundifolia	4395	5868
Lonicera japonica	62	5058
Aristida spp.	1354	4249
Smilax spp.	479	4047
Quercus spp. (red)	1437	3035
Rubus spp.	42	2425
Quercus spp. (white)	208	1214
Viburnum spp.	0	1011
Prunus serotina	208	809
Smilacina racemosa	0	607
Cercis canadensis	0	607
Panicum spp.	604	0
Asarum canadense	83	405
Carya spp.	333	405
Liquidambar styraciflua	0	405
Pinus taeda	292	202
Cornus florida	271	202
Potentilla spp.	229	0
Callicarpa americana	0	202
Chimaphilia maculata	62	202
Desmodium spp.	0	202
Nyssa sylvatica	125	202
Liriodendron tulipifera	83	202
Miscellaneous	2189	404
Total	.5288	410461

In summary, two upland hardwood stands with a history of high grading were subdivided into tree, shrub, and groundlevel strata and were inventoried. Basal areas were 90 and 72 ft^2, respectively, at Site 1 and Site 2. The latter apparently having been cutover fairly recently because it contained more intolerant plants in the understory. All three strata contained major components of red and white oaks. Sweetgum was notable by its absence at Site 2.

Height Growth Patterns of Planted Pine & Hardwood Rootstocks

Average height trends of planted pine and the developing dominant hardwoods for Site 1 are shown in Figure 1. At Site 1, the average height of the pine exceeds that of any of the hardwoods by age 4. Dogwood and hickory, which were a major prelogging component (Table 1), responded rapidly to overstory removal, but by age 3 their height growth is leveling off. This is due in part to the growth characteristic of the species, as well as the developing competition from the pine and other hardwoods. The dogwood and hickory will not likely remain a major component in the overstory,

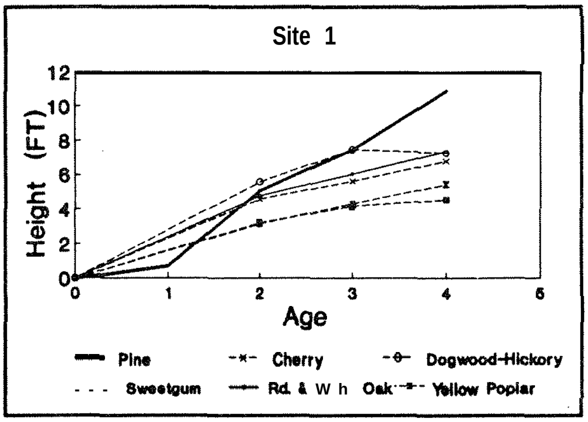

Figure 1. **Average height trend of planted pine and developing dominant hardwoods on Site 1 in Jackson County, Georgia.**

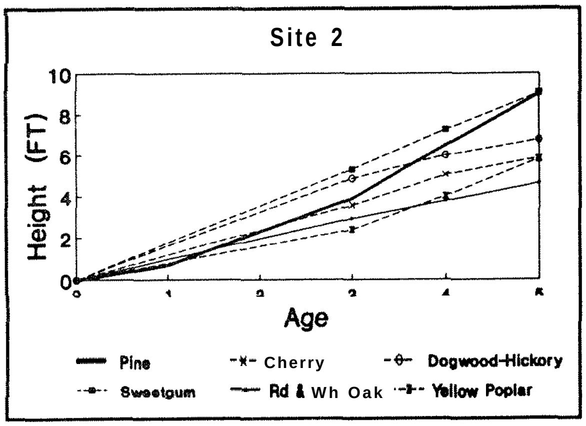

Figure 2. Average height trend of planted pine and developing dominant hardwoods on Site 2 in Jackson County, Georgia

although both will persist for a long time in the understory. The average height growth of cherry and oak (red and white) is less than that of the pine, but is not showing a declining trend. The average height of the oak species represents small root stocks originating from seeds as well as coppice. Oaks will remain a major component in this stand for several years. Sweetgum, although it is well adapted for this site, is only a minor component. However, its average height growth rate has been low. This is largely due to the fact that most of the sweetgum on this site originated from seed and not stump sprouts. On this site, it is likely that sweetgum will be able to persist, but will always be a minor component of the stand.

On Site 2, sweetgum and pine both have an average height of near 8 ft. However, the growth trajectory of pine vs. sweetgum suggests that on average pine will dominate on this site (Fig. 2). Dogwood and hickory also have a greater average height than all other hardwoods except sweetgum. However, as on Site 1, their height growth rate is decreasing and it is unlikely that they will remain a dominant or codominant component of the stand. On eroded sites such as were found in this study, loblolly pine is well adapted to compete for site resources with the common hardwood species found on upland Piedmont soils.

Because the average height of a species reflects the height of rootstocks originating from seeds as well as stump sprouts, it is not a good measure of the crown position a species will maintain in the developing canopy of the stand. The taller stems that capture a place in the canopy will be the major competitors with pine for the next 35-40 years. Average height of the tallest rootstock of each species is expected to be more indicative of a species capacity to maintain a dominant position in the developing canopy. The trend observed for the average height of the tallest stem of each species observed in each plot on Site 1 is shown in Figure 3. When this approach is taken it does not appear that loblolly pine has dominated this site. However, the growth rate of loblolly in the last 2 years has been more rapid than that of the associated hardwoods. This suggests that many of the loblolly seedlings will eventually gain a dominant position

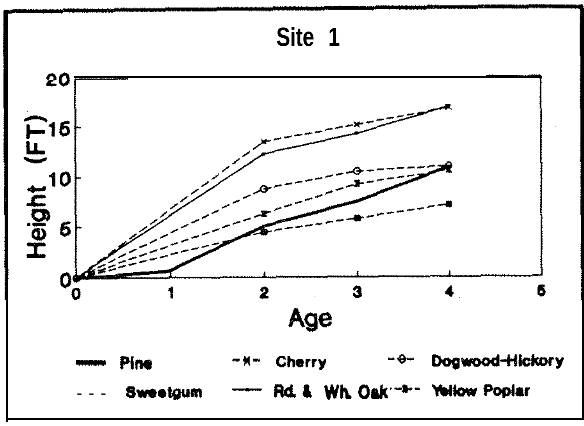

Figure 3. Trend observed for the average height of the tallest stem for each species on Site 1.

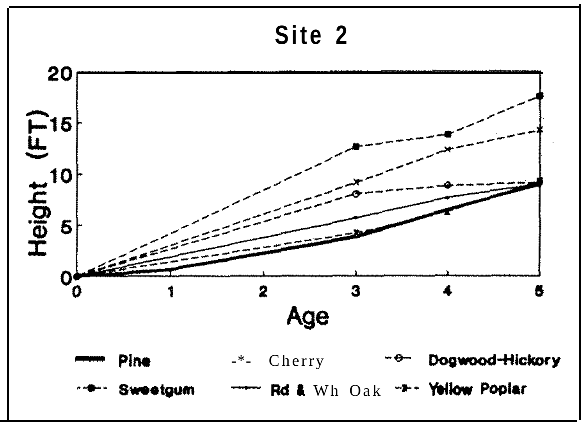

Figure 4. Trend observed for the average height of the tallest stem for each species on Site 2.

in the crown. This approach also indicates that red oak, white oak, and black cherry are currently the major competitors. On these sites, it is expected that black cherry will slow in its growth and not remain a major component, while the oaks will continue as the major competitor of the pine.

On Site 2, comparing the height of the pine with that of the average maximum stem height of each hardwood species indicates that the pine component is about equal in height to that of red oaks, white oaks, yellow poplar and the dogwood-hickory components (Fig. 4). However, the apparent growth rate of pine in the last year suggests that pine height will soon exceed the height of these species. The height of the pine is much less than the average maximum height of the sweetgum and black cherry components. Because of the frequency of sweetgum on Site 2 and the fact that its height growth rate can be nearly comparable to pine, it will take the pine many years to fully capture the dominant crown position in this stand.

Crown Development Predictions

A second objective of this study was to determine what measures can be taken at ages 2 or 3 that reflect capture of the site by hardwoods versus pines. The results of these comparisons are preliminary because only age 4 and 5 data are available to correlate with age 2 and 3 measures on Sites 1 and 2, respectively. Two early assessment measures were made: numbers of hardwood roots tocks and crown area. Age 2 measures of these variables were related to age 4 measures of hardwood crown area that had developed on each subplot oh Site 1. On Site 2, the first measurements were not taken until age 3, so ages 3 and 5 were used to develop the same relationship. The relationship between the total crown area on each plot at age 4 or 5 versus number of rootstocks at age 2 or 3 is shown in Figures 5 and 6 for Site 1 and 2, respectively. On Site 1 there was no significant relationship between early measures of the number of rootstocks at age 2 with the amount of crown area that had developed by age 4 (Fig. 5). This is in contrast to Site 2 for which there was a strong curvilinear relations between total hardwood crown area at age 5 and the number of root s tocks at age 3 (Fig. 6). The relationship observed on Site 2 is consistent with that reported by McMinn et al. (1988) except they reported a linear relationship.

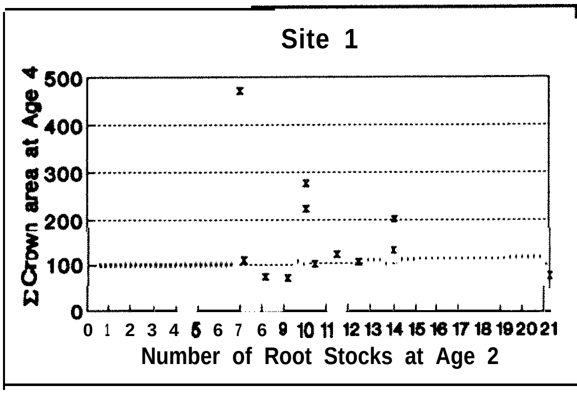

Figure 5. Total crown area per plot at age 4 vs. number of rootstocks at age 2 on Site 1.

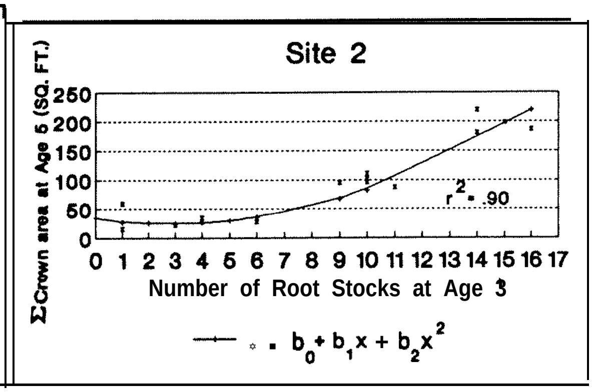

Figure 6. Total crown area per plot at age 5 vs. number of rootstocks at age 3 on Site 2.

The relationship of crown area determined at age 4 or 5 with early measures of crown area (age 2 or 3) showed a consis tent relationship for both Site 1 and 2 (Fig. 7, 8). In fact, the data from both sites could be combined and little accuracy in prediction would be lost. These results suggest that for evaluation of hardwood competition at age 2 or 3, that measures of crown area (crown width) would be preferred over counting number of rootstocks.

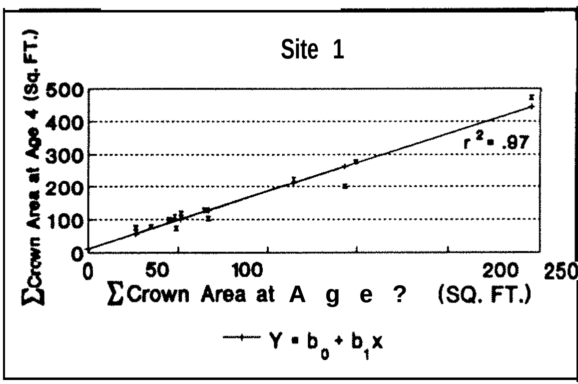

Figure 7. Trend for crown area at age 4 vs. crown area at age 2 for Site 1.

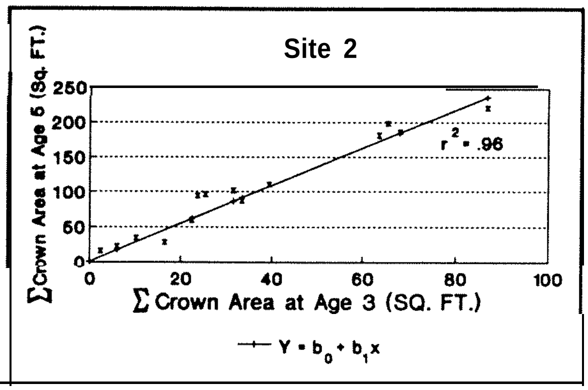

Figure 8. Trend for crown area at age 5 vs. crown area at age 3 on Site 2.

Discussion And Conclusions

In this study, a hardwood stand was harvested and 1-O loblolly pine were planted without any site preparation. Height growth of hardwood arising from coppice has been faster than that of the planted loblolly pine. However, the growth rate of the pine now is as fast, or faster, than the dominant hardwood species, and clearly loblolly will be a major component of both of these stands in the future. Height growth rates of hardwood species such as dogwood, hickory, and yellow poplar (Site 1) are beginning to slow down. Their persistence in the developing stands will be a function of their tolerance to shade. Black cherry has exceptionally fast growth from coppice, but is also beginning to slow in height growth. Due to this--its shade intolerance, intolerance to dry soils, and its succeptibility to foliage and stem fungi infestations in this part of its range (Fowells 1965)--it is expected that black cherry will not be a major component in the developing stand. Instead, it will be a minor component just as it was in the previous stand. Understanding the ecophysiology of species such as yellow poplar, black cherry, and dogwood is helpful in determining if the species should be considered a major long-term competitor with planted pines. For instance, on sites with deep, well-drained fertile soils, black cherry and yellow poplar would be expected to be the major long-term (rotation length) competitors.

Two early measures of hardwood which were used to assess the extent hardwoods had captured these two sites were evaluated. These include number of rootstocks and crown area. Crown area measures made at age 2 or 3 were more significantly related to hardwood crown areas measured at ages 4 or 5, then the number of rootstocks measured at age 2 or 3. Most hardwood assessments are currently made by simply counting the number of hardwood rootstocks or stems. This work suggests that measures of crown area at age 2 or 3 would provide better assessment of the potential hardwood competition problems. Measurements of hardwood crown areas also lends itself to being done from aerial photographs. Species determinations would not be easy to obtain from aerial photographs. Based on this work, the elements of a good early (year 2 or 3) assessment of future hardwood competition would include:

1. A determination of which hardwood species should be considered as long-term competition on the site under evaluation;

2. Measures of the crown width (area) of the long-term competitors; and

3. The position of the planted pine in the developing canopy.

This study will be continued into the future so the early measures of crown area can be related to the hardwood basal area that develops at age 8-10. Hardwood basal area determined at these ages can then be used to estimate pine yield losses due to hardwood competition.

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AGE AND SIZE STRUCTURE OF A SHORTLEAF PINE-OAK STAND IN THE OUACHITA MOUNTAINS--IMPLICATIONS FOR UNEVEN AGED MANAGEMENT[1]

Michael G. Shelton and Paul A. Murphy [2]

Abstract. This paper reports some initial findings of a study implemented to test uneven-aged management in the shortleaf (Pinus echinata Mill.) pine stands of the Ouachita Mountains of Arkansas, and to determine the threshold levels for hardwood retention within a pine management system. A preharvest inventory and age analysis of 526 trees provided data on the age and size structure and age-size relationships in a mature, second-growth shortleaf pine-oak (Quercus spp.) stand. The results showed that nearly all the pines were established in the 40 years following harvest of the virgin forest in the 1910s, and most of the oaks became established with the advent of fire control in the 1920s and 1930s. A small remnant of the virgin forest was still present. Diameter distribution for shortleaf pine showed peaks at 5 and 11 inches dbh, whereas hardwoods had a reverse-J distribution. The woody understory consisted mainly of shrubs, and the tree. species present showed a shift to the more shade-tolerant species. The trees showed positive age-size relationships. Several problems are foreseen in implementing uneven-aged management in the stand conditions described here: (1) some hardwood control will be necessary; (2) a reverse-J distribution must be developed for shortleaf pine; and (3) the response of suppressed shortleaf pine is questionable.

Introduction

Shortleaf pine (Pinus echinata Mill.) is found throughout the South and makes an important contribution to the timber economies within most of its range, ranking second to loblolly pine (P. taeda L.) in contribution to the total softwood volume in the South. Arkansas contains more shortleaf pine volume than any other state, and most of this volume is concentrated in the seven counties that make up the Ouachita Mountains. This region alone accounts for one-tenth of the total shortleaf volume in the entire South (McWilliams et al., 1986; Hines 1988).

In addition to shortleaf pine, scenic beauty and forest recreation abound in the Ouachi ta Mountains. These nontimber resources are heavily used because the Ouachitas are the closest mountains to a number of population centers located in the surrounding Coastal Plain. society's use of these nontimber forest resources will undoubtedly increase in the future.

Both in the Ouachita Mountains and elsewhere, clearcutting has caused more furor among the public and the forestry profession than any other forestry practice (Kluender

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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and Green 1990). In areas of high visibility, clearcutting's negative impact on scenic beauty is often considered undesirable (Stignani 1986). In contrast, if suitable species and stand conditions are present, uneven-aged management with single-tree selection will produce the least noticeable disturbance of any management system (Marquis 1978). Uneven-aged management would allow a continuous but irregular forest cover to be perpetuated, potentially achieving an acceptable balance between timber and certain non-timber forest resources.

Unfortunately, our knowledge about managing shortleaf pine in uneven-aged systems is limited (Murphy et al., 1991). Techniques and guidelines developed for loblolly-shortleaf stands at the Crossett Experimental Forest in the Coastal Plain of Arkansas (Reynolds 1959, 1969; Reynolds et al., 1984) may be adaptable to the shortleaf pine stands in the Ouachita Mountains. However, most of the Crossett experience applies to managing existing uneven-aged stands or rehabilitating understocked, cutover stands, whereas the Ouachita Mountains have mostly mature, second-growth stands that have developed an even-aged character. In 1988 the Southern Forest Experiment Station and the Ouachita National Forest implemented a study to test traditional uneven-aged management in the shortleaf pine stands of the Ouachita Mountains and to determine the threshold levels for hardwood retention within a pine management system. This paper is an interim report on the initial stand conditions and the implications of these conditions for applying uneven-aged management successfully.

Methods

Study Area

The study was installed in the Winona Ranger District of the Ouachita National Forest in a mature, second-growth shortleaf pine-oak stand located near the Lake Sylvia Recreational Area in Perry County, Arkansas. This area is typical of much of the forested landscape of the Ouachita Mountains, where the upland forests are dominated by shortleaf pine.

The study area is oriented along an east-west ridge, which is typical of the physiography of the Ouachitas. Elevation ranges from 640 to 790 ft above sea level, a 150-ft difference in relief. Plots are located in the following slope positions: lower, middle, and upper north slope and upper south slope. Slopes range from 8 to 21 percent, with the steepest slopes in the side-slope positions. Aspects of individual plots are north to northwest on the north-slope positions and southeast to southwest on the south-slope position.

Soils of the study area are mapped as the Carnasaw and Pirum series, both Typic Hapludults. These are well-drained, moderately deep soils that developed in colluvium and residuum weathered from sandstone and shale. Natural fertility and organic matter are low, and the soils are strongly acidic. The site index for shortleaf pine averaged 57 ft at 50 years and ranged from 53 to 64 ft, typical of upland sites in the Ouachita Mountains. The lower north slope was slightly higher in site index than the other three slope positions (61 versus 56). The site index averaged 53 ft at 50 years for white oak (Quercus alba L.) and 54 ft for black oak (Q. velutina Lam.).

This second-growth stand originated after harvest of the virgin shortleaf pine forest, probably in the 1910s. The Fourche River Lumber Company, Bigelow, Arkansas, was active in the vicinity from 1904 to 1921 (Smith 1986). Typical harvests of that era involved cutting the pines to a 14-inch stump limit and perhaps harvesting the higher quality red and white oaks. A ragged, cutover stand composed of submerchantable pines (< 12 inches in dbh) and scattered, low-quality hardwoods remained after harvest. Periodic fires were common both before and after harvest of the virgin forest. Although these fires undoubtedly killed much of the shortleaf regeneration, they also created an ideal pine seedbed and prevented the establishment of a significant hardwood component. During the four decades following harvest of the virgin forest, enough regeneration escaped the periodic fires to establish an irregular-aged shortleaf pine stand. The sprouting ability of shortleaf pine (Mattoon 1908) was undoubtedly an important factor in its successful establishment during this period. Fire control, implemented in this region in the 1920s and 1930s (Smith 1986), increased the survival of newly established pines, but also favored the establishment of a significant hardwood component.

Pine basal areas averaged 90 ft^2/ac on the 25.6-ac study area (Table 1). Individual 1.6-ac plots ranged from 66 to 110 ft^2/ac of pine basal area; the highest values were on the lower north slope and the upper south slope. Hardwood basal areas averaged 32 ft^2/ac and ranged from 21 to 48 ft^2/ac. For individual plots, hardwood basal area varied inversely to that of pine (correlation coefficient of -0.92). The oaks accounted for 84 percent of the total hardwood basal area. White oak was the most prevalent hardwood species, with lesser amounts of post oak (Q. stellata Wang.), black oak, blackjack oak (Q. marilandica Muench.), and southern red oak (Q. falcata Michx.). The remaining 16 percent of the hardwood basal area was composed of various hickories (Carya spp.), red maple (Acer rubrum L.), serviceberry [Amelanchier arborea (Michx. f.) Fern.], blackgum (Nyssa sylvatica Marsh.), and dogwood (Cornus florida L.). The understory was composed of tree saplings (mainly of the more shade-tolerant species) and a variety of common shrubs--huckleberries (Vaccinium spp.) and hawthorns (Crataegus spp.).

Although specific details are not known, the study area showed little evidence of recent management. Some charring of pine stems was evident on the south-slope position but not elsewhere. The only thinning known to the authors occurred around 1950.

Study Design And Sampling

The study area encompasses 16 plots, each 1.6-ac, arranged in a randomized complete block design with four blocks and four plots per block. Each plot consists of an interior 0.5-ac net plot and the surrounding 1.1-ac isolation strip. Treatments include three levels of hardwood retention (0, 15, and 30 ft^2/ac of basal area) in combination with a uniform pine basal area of 60 ft^2/ac. The treatment with 15 ft^2/ac of hardwoods was implemented with two types of spatial arrangements of residual hardwoods (scattered and clumped). Treatments were imposed by harvesting the plots during the 1988-89 dormant season.

Table 1. Stand properties of a second-growth shortleaf pine-oak stand in the Ouachita Mountains.

Property	Shortleaf pine	White Oaks	Red oaks	Other trees	Total
Basal area (ft^2/ac)	90.1	18.2	8.8	5.3	122.4
Trees/ac	144.6	92.4	39.8	35.9	312.7
Mean dbh (inch)	10.1	5.6	6.0	4.9	--
Mean height (ft)	59.5	44.5	40.9	37.5	--
Mean crown diameter (ft)	16.4	16.1	15.1	13.8	--

A preharvest inventory of all trees over 3.5 inches in dbh was conducted during the fall of 1988. Trees were tallied by the following species and species groups: shortleaf pine, white oaks (white and post oaks), red oaks (black, blackjack, and southern red oaks), and other trees (blackgum, red maple, hickories, serviceberry, and dogwood). The net plots and isolation strips were inventoried separately but these data were combined to describe the initial stand conditions.

Age determinations were made during March and April 1989 as part of the postharvest inventory. On each plot, the age of one tree in each l-inch dbh class was determined for each species and species group present by taking an increment core at 4 ft in height. Cores were stored under refrigeration until they were aged. Rings were counted in the laboratory under strong light and magnification after cutting a clean surface on each core. In addition, the width of each lo-year interval of radial growth was measured for each core. Determination of hardwood age was restricted to the oaks and largely excluded blackjack oak, which was typically unsound. The larger oaks (i.e., over 14 inches dbh) were probably underrepresented in the sample because few were sound to the pith. The time required for a tree to reach 4 ft in height was assumed to be 3 years for all species.

Most trees in this age sample were randomly selected from an individual tree tally of all residual trees on each net plot. Occasionally a tree on an isolation strip or just outside a plot was selected to obtain a particular dbh class or species. Some supplemental sampling was done during the summer of 1990, but ring counts and radial increment measurements were stopped at the 1988 reference point. In total, the ages of 294 pines and 232 oaks were determined.

To determine the age structure of the stand, the distribution of the sample trees by lo-year age classes and l-inch dbh classes was calculated for pine, white oaks, and red oaks, and each distribution was then weighted by the observed diameter distribution. The weighted number of trees in each age-dbh class was then summed to obtain stand totals for a specific age class.

To obtain an estimate of the woody understory in the initial stand, 120 small plots (30 per block) were sampled during September 1989 in the undisturbed stand located just outside the established plots. Saplings were tallied on circular, 0.01-ac plots by dbh class (1-, 2-, and 3-inch) and species or species group. Seedlings were tallied on nested milacre subplots by species or species group and the following size classes: ≤ 0.5 ft in height; 0.6 to 2.5 ft; 2.6 to 4.5 ft; and ≥ 4.6 ft in height and ≤ 0.5 inches in dbh.

The shortleaf site index was calculated from Graney and Burkhart (1973); the white and black oak site index from Farrar (1985). Total height and crown dimensions of species and species groups were determined from 379 pines and 265 hardwoods.

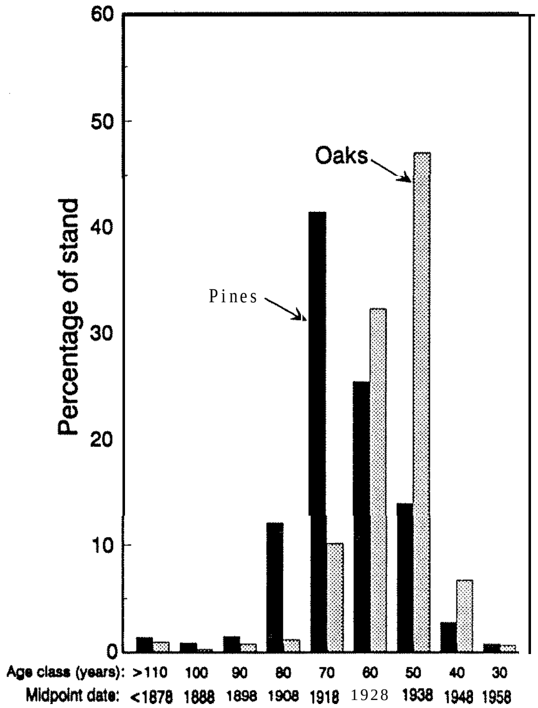

Figure 1. Age structure of pines and oaks of a second-growth pine-oak stand in the Ouachita Mountains.

Results

Age Structure

Trees in this irregular-aged stand developed from three different sources: (1) a remnant of the virgin forest (trees that were submerchantable at the time of harvest); (2) seedlings and saplings that existed as advanced reproduction when the virgin forest was harvested; and (3) seedlings that became established after harvest. Most of this stand belongs in the third category. For example, more than 90 percent of the pines were established in the four-decade period following harvest, represented by the 50- to 80-year age classes (Fig. 1). The most frequent age class was 70 years (midpoint 1918), which accounted for 41 percent of the total pine density. Pine establishment decreased rapidly after the period represented by this age class and virtually ceased at the 40-year age class (midpoint 1948). Most likely, pine regeneration occurred during this time, but stand conditions were not favorable for subsequent development and survival. Oaks were somewhat younger than the pines, and more than 90 percent of the oaks became established during the four-decade period represented by the 40- to 70-year age classes. The 50-year age class was the most frequent, accounting for 47 percent of the oaks. The paucity of young trees in the overstory indicates that regeneration and subsequent development have been restricted for both the pines and the oaks over the past 30 to 40 years.

A remnant of the virgin forest was still present in the second-growth stand. Two percent of the pines and 1 percent of the oaks were in the 100-year age class and older. Several oaks and pines were nearly 200 years old. Many of the larger oaks (i . e. , over 14 inches in dbh) were hollow, and few could be aged to the pith. Old-aged pines were apparent from their slick bark, flat or decurved branch angles, and flat upper crowns. Old-aged hardwoods usually had robust, open-grown crowns, which undoubtedly reflects the open nature of the virgin forest of this region (Smith 1986). American Lumberman (1904) reported that the virgin forests of this area contained an average of only 5,000 bd f t of pine and 1,000 bd f t of hardwoods (log rule not specified). Curiously, this volume is close to the stocking levels maintained in managed uneven-aged stands.

Past harvests within the second-growth stand may have modified the existing age-class distribution, particularly if they focused on a specific size class (e.g., pulpwood only) or species (e.g., red oaks for firewood). The extent of such influences is not known.

Comparable age analyses for the second-growth stands of this region are not generally available. Turner (1935) conducted an age analysis of three virgin shortleaf stands in the Ouachita Mountains and found that about two-thirds of the trees in those stands became established during a one-decade period, compared with about 40 percent in this second-growth stand. However, competition mortality might eventually narrow the age-class distribution in this second-growth stand. In Turner's study, the oldest tree of the virgin stands was twice the age of the youngest tree. Turner emphasized the importance of natural catastrophes, frequent tornadoes and periodic fires, in modifying the composition and structure of the virgin forest of this region.

Size Structure

Each species and species group had a unique diameter-class distribution, reflecting differences in shade tolerance, growth rates, and age structure (Fig. 2). Shortleaf pine displayed somewhat of a binomial distribution, with peaks occurring at 5 and 11 inches in dbh; few pines were larger than 18 inches. Hardwoods had a reverse-J distribution. White oaks were the most common hardwood group, and they dominated the smaller diameter classes. Few hardwoods were more than 12 inches in diameter. In the 14-inch diameter class and larger, hardwood trees averaged 1.8/ac, and most of these trees were undoubtedly present when the virgin forest was harvested. White and post oaks were the most common of the larger hardwoods, along with occasional blackgums. Most of the black and southern red oaks in the stand apparently became established in the second-growth stand, since few large trees were observed in these species. However, as noted in reference to age structure, the effects of selective harvesting in the second-growth stand on this size-class distribution are not known.

The woody understory was composed of more than 13,000 stems/ac (Table 2). About two-thirds of the understory density were shrubs, principally *Vaccinium* spp. Seedlings and saplings of various tree species represented in the overstory were also common in the understory, but there was a shift to the more shade-tolerant species. For example, species in the other

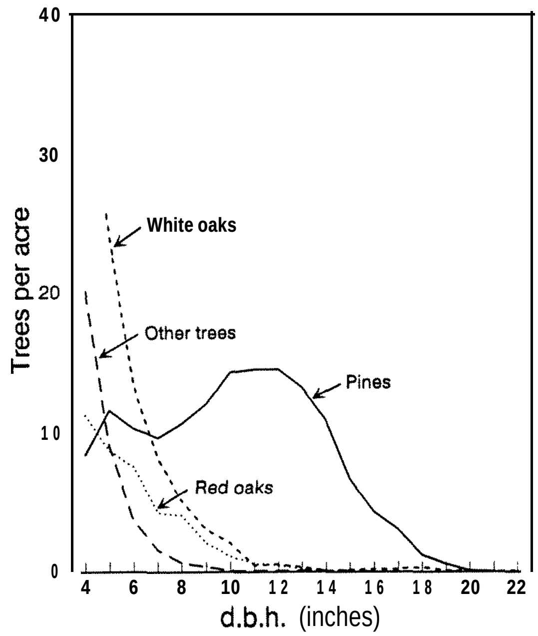

Figure 2. Diameter distribution of a second-growth pine-oak stand in the Ouachita Mountains.

trees group (e.g., red maple, blackgum) accounted for 44 percent of the understory density (tree species only), in contrast to only 11 percent of the overstory. The shade-intolerant pines were the most infrequent members of the understory, accounting for only 9 percent of the understory-tree density. There were 274 pines/ac in the understory, and most were less than or equal to 0.5 ft in height. Pine seedlings were not very evenly distributed throughout the stand; they were most common on the south-slope position. Milacre-stocking averaged only 9 percent. Understory pines in this stand displayed traits similar to those Wahlenberg (1960) described for suppressed loblolly pines that had developed in overstocked pine-hardwood stands. That is, seedlings and saplings were in a low state of vigor and many had lost apical dominance. Clearly, understory pines represent an ephemeral component of this stand; they become established but survive for only a short time. Understory oaks displayed a size distribution similar to that of the pines, but at higher density levels, indicating intermediate tolerance to shade.

Age-Size Relationships

In even-aged stands, size and age are not related, because the trees became established during a relatively short time interval. Despite the uniformity in age structure of even-aged stands, considerable size-class variation can occur because of differences in genetics and environmental factors. In contrast, a positive relationship often occurs between age and size in uneven-aged or irregular-aged stands: small trees are generally young trees and large trees are usually old trees. However, considerable variation occurs in this relationship because of variation in the same genetic and environmental factors that function in even-aged stands.

The age-size relationships for the species and species groups in this stand had coefficients of determination ranging from 0.20 to 0.44 for dbh and 0.13 to 0.44 for height (Table 3). Pine had the strongest relationship of all species, followed by white oak. The lower coefficients of determination for white oak and post oak may partially reflect our inability to age the larger trees in the stand. Based on these results, a typical 70-year-old pine would be 11.8 inches in dbh and 63 f t in height, compared with 9.6 inches and 57 ft for a similarly aged white oak.

Table 2. Size-class distribution of the woody understory of a second-growth pine-oak stand in the Ouachita Mountains.

Size class (height or dbh)	Shortleaf pine	White oaks	Red oaks	Other trees	Shrubs	Total
	(stems/ac)					
≤ 0.5 ft	217	325	250	667	1,558	3,017
0.6-2.5 ft	42	908	217	767	7,133	9,067
2.6-4.5 ft	0	125	25	133	525	808
≥ 4.6 ft and ≤ 0.5 inches dbh	0	0	8	50	50	108
1-inch dbh class	8	7	11	64	7	97
2-inch dbh class	4	31	4	47	2	88
3-inch dbh class	3	51	7	29	0	90
Total	274	1,447	522	1,757	9,275	13,275

A factor contributing to the positive age-size relationships in this stand is that stand conditions have changed continuously following the harvest of the virgin forest. Understocked, open conditions existed after that harvest, and in-place and newly established seedlings developed in a relatively free-to-grow environment. In contrast, seedlings becoming established later grew under competition from the older trees.

The growth pattern for individual trees within this stand is illustrated in Figure 3, which shows the diameter increment for shortleaf pine. Trees becoming established shortly before and after the harvest of the virgin forest (i.e., the 80-year class) exhibited the highest rates of diameter increment over the first few decades. Subsequent increments of this age class showed the linear decline typical of increasing tree girth and increasing stocking levels within the stand. During the eighth decade of development, diameter increment in this age class had declined to a rate of only 0.08 inches/yr . By contrast, diameter increments of the 40-year age class were only one-quarter to two-thirds of the corresponding rates of the 80-year class. It is hoped that the low stocking levels maintained through uneven-aged management will foster the higher growth rates displayed by the early waves of regeneration that developed in the second-growth stand.

Regression analysis of the diameter-increment data yielded the following equations [presented with the standard error of estimate (SEE), coefficient of determination (r^2), and degrees of freedom (df)] for shortleaf pine [1] and white oak [2]:

$$D_i = 0.0278 + 0.00354A_{88} - 0.003358, \qquad [1]$$
$$SEE = 0.067, \quad r^2 = 0.51, \quad df = 1{,}776$$

$$D_i = 0.0100 + 0.00141A_{88} + 0.498/A_1 \qquad [2]$$
$$SEE = 0.045 \quad r^2 = 0.17 \quad df = 746,$$

Table 3. Regression of tree size and age for a second-growth pine-oak stand in the Ouachita Hountains.

Species or group	Regression coefficient [1] b_0	b_1	Standard error of estimate	Degrees of freedom	Coefficient of determination
			(dbh)		
Shortleaf pine	23.8	843	3.44	293	0.44
White oak	18.2	-605	2.22	132	0.42
Post oak	14.9	-488	2.49	40	0.30
Red oaks [2]	16.9	-498	2.46	57	0.20
Combinedoaks	16.4	-508	2.40	233	0.30
			(height)		
Shortleaf pine	102.7	-2,783		261	0.44
White oak	85.7	-1,995	9.5	108	0.27
Post oak	62.3	-1,005	8.3	39	0.14
Red oaks [2]	17.9	-1,426	9.2	54	0.13
Combinedoaks	72.3	-1,273	9.7	205	0.13

[1] Equation is $Y = b_0 + b_1/\text{age}$, where Y is dbh in inches or height in ft, and tree age is in years.

[2] Black oak and southern red oak combined.

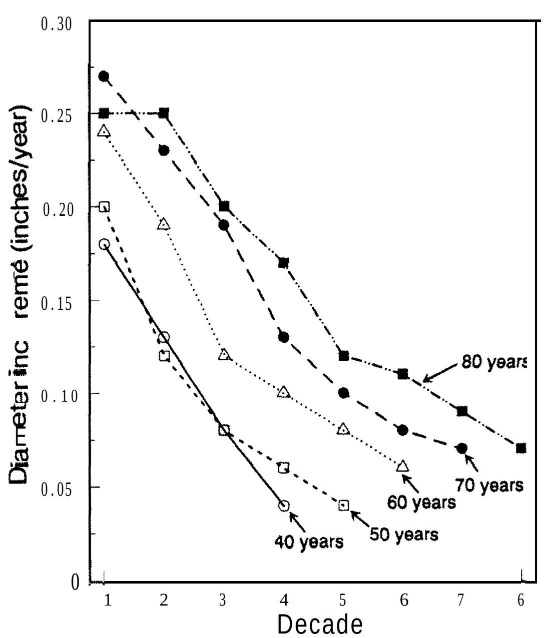

Figure 3. Mean diameter increment (inside bark) at 4 ft in height by decade and age class for 273 shortleaf pines in a second-growth pine-oak stand in the Ouachita Mountains.

where D_i = annual diameter increment (inside bark in inches at 4 ft in height) occurring during the decade period i ;

A_{88} = tree age in years in 1988, restricted to trees < 86 years old; and

A_i = tree age at midpoint of the decade period i.

Independent variables in each equation were significant at the 0.001 probability level when fitted last; the interaction terms were not significant and were not included in the equations. The coefficient of determination for white oak, which was typical of the other oaks, was considerably lower than that for pine. Although the two species displayed similar patterns, the best fits were obtained using the linear expression for A_i for shortleaf pine and the reciprocal for white oak.

Implications for Management

Successional Trends

Shortleaf pine is the dominant species in the Ouachita Mountains, both currently and historically. However, the perpetuation of this forest type is strongly dependent on periodic disturbance, which occurs through several different mechanisms. Common forms of natural disturbance include physical factors, such as fire and tornadoes, and pathological factors, such as insects and diseases. Humans also contribute to disturbance through timber harvests, forest management, and fires, both prescribed and otherwise. The significance of hardwoods in the natural succession of the pine-dominated forest is well known (e.g., Wahlenberg 1960, Blair and Brunett 1976, Huston and Smith 1987). Without periodic disturbance, successional development is characterized by the progressive replacement of pines with hardwoods. The progression to a hardwood-dominated forest reflects differences in the relative physiology of the species, differences that affect establishment, development, and survival. Compared with pines, most hardwood species have a greater tolerance to persist and develop in the shade.

Successional trends were apparent in the development of this second-growth pine-oak stand. Pine establishment dominated the first four decades following harvest of the virgin forest. However, once fire control was implemented in the 1920s and 1930s, a significant hardwood component became established, and pine survival and development declined. The presence of old-aged hardwoods in the second-growth forest is evidence that a hardwood component was present in the virgin forest. In fact, early reports of the timber resources of this region indicate that the ratio of pine and oak timber volumes was 6:1 (American Lumberman 1904).

Without some type of species control, the application of uneven-aged management to shade-intolerant species, such as the southern pines, will cause a shift to shade-tolerant species (Blair and Brunett 1976). This compositional change is typically a major limitation in the uneven-aged management of intolerant species (Franklin 1978). With the southern pines, successful application of uneven-aged management has been associated with aggressive hardwood control (Reynolds 1959, 1969; Reynolds et al., 1984). Herbicides are the principal means of hardwood control, because periodic fires may destroy pine regeneration along with the hardwoods. However, the sprouting ability of young shortleaf pine may increase the possibilities for incorporating a prescribed-fire program within the uneven-aged management of this species.

Hardwoods occurring in uneven-aged pine stands may adversely affect both pine growth and regeneration. For example, Grano (1970) observed that hardwoods reduced the radial increment of the pines in uneven-aged loblolly-shortleaf stands in the Coastal Plain by 30 to 40 percent in dry years. However, the most critical effect of hardwoods in uneven-aged stands will undoubtedly be inhibiting pine regeneration. Currently, no guidelines exist for the maximum levels of hardwoods that can be retained within an uneven-aged pine stand if pine regeneration and recruitment into larger size classes is to be adequate.

Response of Suppressed Trees

One of the basic tenets of uneven-aged silviculture is that small, suppressed trees will respond to release and eventually develop into sawlog-crop trees . However, the levels of suppression are considerably less in well-regulated uneven-aged stands than in even-aged stands, where higher stocking levels are maintained. In stands with high stocking, suppression mortality typically occurs in the smaller size classes. Thus, an uneven- or irregular-aged stand will develop an even-aged size-class distribution unless continuously managed under uneven-aged guidelines. For these reasons, the typical reverse-J distribution will not be present in stands of intolerant species that are not actively under uneven-aged management. It is quite likely that the stand described here had an uneven-aged structure in the 1930s and 1940s. Stand conditions were probably similar to those described by Reynolds (1959) during the early days of uneven-aged management of the Crossett Experimental Forest.

Suppressed pines in the smaller size classes were common in this stand. An average of 62 pines/ac were in the subsawlog component (4- to 9-inch dbh classes). Most of these trees had become established late in the development of the second-growth stand. Because they were latecomers, many had been suppressed throughout most of their development and therefore had poor form and small, thin crowns. Do these suppressed trees have the potential to become high-quality sawlog-crop trees?

Mixed results have been observed following the release of suppressed trees for both pines (Chapman 1923, Chaiken 1941, Reynolds 1952, McLemore 1987) and hardwoods (Minckler 1957, Schlesinger 1978, McGee and Bivens 1984). Most commonly, response is highly variable and difficult to predict. Obviously, response is affected by a host of factors (e.g., species, age, degree of suppression, crown features and position, and extent of release). Height growth seems to be less responsive than diameter, and pronounced epicormic branching is a problem in hardwood species. Older trees appear to require longer recovery periods and recovery seems to be less dependable than in younger trees. Pines generally, seem to be more responsive than hardwoods.

In many cases, the recovery of suppressed loblolly and shortleaf pines has been dramatic following release. Evidence of this response was common in the second-growth stands Reynolds (1952) examined in southeastern Arkansas. McLemore (1987) also found that suppressed loblolly pines (15 to 40 years old and with small, thin crowns) recovered rapidly following drastic release; response was most highly correlated with live-crown percentage and stem diameter at the live-crown base. McMinn (1988) found that 65-year-old shortleaf pines growing in pine-hardwood stands generally responded to hardwood removal. Response was related to crown class and pretreatment growth. Likewise, Murphy and Shelton (1991) observed that the degree of release and pretreatment growth influenced the response of residual loblolly and shortleaf pines following diameter-limit cutting. One of the principal objectives of this study is to monitor the response of relatively old, suppressed shortleaf pines on poor sites.

Conclusions

Harvest of the virgin forest and the implementation of fire control were the two most significant events affecting the development of this second-growth stand. These same events exerted a similar influence on stand development throughout the South. Age analysis indicated that pine regeneration and successful development continued through the first four decades following harvest of the virgin forest. A significant hardwood component became established after the initiation of fire control and was associated with a sharp decline in pine development and survival.

This second-growth stand probably had an uneven-aged structure in the 1940s, with stand conditions similar to those encountered by Reynolds when he initiated the uneven-aged management of the second-growth pine stands of the Crossett Experimental Forest. Uneven-aged management in this Ouachita stand probably would have been easily implemented under these stand conditions. However, during subsequent stand development, hardwoods were not controlled and pine stocking levels were not regulated through periodic harvests, which terminated the regenerative portion of the uneven-aged cycle.

Most experience in uneven-aged management pertains to rehabilitating understocked stands or managing stands that already have a reverse-J structure. This mature, second-growth stand poses unique problems that must be addressed in implementing uneven-aged management. First, a significant component of midstory hardwoods must be controlled. Guidelines from the Crossett experience call for complete hardwood control. The allowable deviation from these guidelines is not currently known, but is likely to be small. Until more is known, focusing uneven-aged management on sites with inherently low levels of competition (e.g., the xeric, south-facing slopes) seems to be a biologically sound option. Second, a reverse-J structure must be developed, which depends on securing pine regeneration and providing an environment suitable for subsequent development. This balanced structure may take several decades to develop. Third, the response of the small, suppressed trees that are 40 to 60 years old is questionable and may have long-lasting effects on growth and yield and the sustainability of future harvests. If suppressed trees do not respond, an alternative strategy for conversion must be developed.

Inventories and regeneration surveys will be conducted in this study area in the future to shed light on the unique problems associated with implementing uneven-aged management in mature stands.

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EARLYSTAND DYNAMICS IN A FIELD COMPETITION EXPERIMENT WITH LOBLOLLYPINE, RED MAPLE, AND BLACK LOCUST[1]

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Abstract. A field competition experiment was established in 1989 in the Virginia Piedmont to examine potential yields and competitive relationships in pine-hardwood mixtures and monocultures grown with and without the influence of herbaceous vegetation. The study is designed as a replacement series experiment with loblolly pine (*Pinus taeda* L.) and two hardwood competitors, black locust (*Robinia pseudoacacia* L.) and red maple (*Acer rubrum* L.). After two @owing seasons, differences in mortality due herbaceous vegetation were small, but tree yields were severely impacted. Stands receiving herbaceous control treatments had 2.5x and 3x the stem and crown volumes, respectively, compared with stands without herbaceous control. Herbaceous vegetation decreased the yield of hardwoods more than that of loblolly pine. Yields also varied significantly between stand types with a 6x difference in stem volume between the highest and lowest yielding stands. Yields increased with increasing pine proportion in the stand and were significantly greater in black locust compared with red maple stands. Pines also produced higher yields in mixtures with black locust than in mixtures with red maple. Black locust had significantly higher mortali ty than red maple or loblolly pine seedlings. Crown form of black locust and loblolly pine in mixed stands was modified from that observed in pure stands, and a greater degree of aboveground interaction occurred in these mixtures than in pine-maple mixtures. Tree seedling and herbaceous root biomass was concentrated mostly in the surface 10 cm of soil. Black locust had the greatest root biomass of all tree species and its biomass did not differ in pure vs. mixed stands . Red maple and loblolly pine root biomass was greater in mixtures than in pure stands. Stand dynamics are likely to intensify as crown closure continues in subsequent growing seasons.

Introduction

Pine-hardwood mixtures are naturally-occurring forest types covering much of the Eastern United States (Sheffield et al., 1989). In the Southeast, hardwood species have often been viewed as undesirable competitors in plantations of the economically more important southern pines (see Stewart et al., 1984). However, intensive and expensive efforts to remove hardwood competitors

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from pine stands is successful only for a short period of time, as hardwood encroachment is renewed from seed or stump sprouts (Boyce and Knight 1980, Cain and Yaussy 1984). This experience with hardwood encroachment suggests that silviculturalists should carefully consider the cost-effectiveness and long-term effects of hardwood control treatments in pine plantations. Bacon and Zedaker (1987) found that not only was intensive hardwood control costly, but pine growth may actually benefit from partial hardwood control compared with complete hardwood control.

Recent developments suggest that the culture of pine-hardwood mixtures may be an attractive alternative to pine monocultures in the Southeast. Advances in wood science technology have increased the utilization of hardwood species and, consequently, have increased their stumpage value, making them more comparable in value to pines (Lentz et al., 1989). Pine-hardwood mixtures may also provide a better buffer against uncertain market conditions (Smith 1988). In addition, concerns about biodiversity argue against stands dominated by a single species. Finally, the small nonindustrial private landowners, who own over 60 percent of forest land in the South (USDA 1988), need to have management options available, ranging from pure pine or hardwoods to mixed stands.

Southern forest researchers have demonstrated that they can create a variety of pine-hardwood stands using operationally feasible silvicultural manipulations (Phillips and Abercrombie 1987; Zedaker et al., 1989). It is essential, however, to determine which species combinations and proportions of hardwood and pine species will optimize ecological and economic benefits by maximizing diversity and mutualistic interactions, and also minimizing negative competitive effects. Studies are needed which utilize controlled competition designs that quantify relative yields and investigate the mechanisms which control competitive relationships. Addressing this research problem is a Z-year study in the Virginia Piedmont assessing competitive outcomes and mechanisms in mixed stands of loblolly pine and black locust or red maple, both with and without the effect of herbaceous vegetation.

Methods

The study site is located at the Reynolds Homestead Experimental Research Station in Patrick County, Virginia. A split-plot design was employed in five blocks, each approximately 0.2 ha in size. Four blocks are located on gently-sloping, upland terrain with eroded Ultisols of the Cecil series (Typic Hapludults, clayey, kaolinitic, thermic). The fifth block is located on a level stream terrace with a Chewacla silt loam soil (Fluvaquentic Dystrochrept, fine-loamy, mixed, thermic). All areas of the study were old-fields until treated in the fall of 1988 with a 2-percent solution of glyphosate (applied as Round-up™, Monsanto Corp., St. Louis, MO) to remove existing vegetation.

Whole plots were randomly assigned to either an herbaceous vegetation treatment consisting of planted tall fescue (Festuca arundinacea Schreb.) or a treatment where herbaceous vegetation was controlled. Subplots were randomly assigned to one of nine replacement series combinations including loo-percent mixtures of loblolly pine, red maple, and black locust; as well as 25: 75, 50: 50, and 75: 25 percent mixtures of pine and each hardwood species, respectively.

Loblolly pine and hardwood seedlings (both 1-O stock) were planted in March, 1989. Each subplot contained a total of 48 measurement trees planted at 1x1-m spacing. Replacement series mixtures (50:50 and 75:25 combinations) were planted in a systematic design to insure an equal number of inter- and intraspecific interactions between subplot stands of the same type. The perimeter of each subplot stand was planted with one row of buffer seedlings of equal species proportion to that contained within the stand. Each whole plot was also enclosed by a single row of pines as an additional buffer between measurement trees and the exterior of the plot.

Tall fescue was not seeded until August 1989 to allow seedlings in herbaceous vegetation plots to become established. Grass seed was applied at a rate of 28 kg/ha. Irrigation was also applied during the first growing season to facilitate grass and tree seedling establishment. Applications of a 2 percent solution of glyphosate using a backpack sprayer with a seedling shield, as well as hand-weeding, were conducted as needed to remove herbaceous vegetation on plots receiving herbaceous control treatments.

Root collar diameter, height, and live crown volume were measured on a random, 25 percent systematic sample of seedlings after planting and at the end of the first and second growing seasons in order to assess the yield of each stand. Canopies of all seedlings in plots receiving herbaceous control on one randomly selected block were mapped to determine crown overlap within stands and to assess attributes of crown morphology that may influence competitive relationships. Mapping consisted of measuring the maximum crown spread of each seedling in eight different directions, the height of the live crown, crown shape, and the height at which the crown attained maximum diameter.

Soil cores were extracted using a 8-cm diameter auger in order to estimate root biomass and amount of root overlap in pure stands and 50:50 mixtures on plots receiving herbaceous control treatments. A total of three cores were collected at randomly selected intersections between two seedlings within each stand at three depths: O-10 cm, 10-20 cm, and 20-30 cm. Roots were hand-sorted from the soil, dried, and weighed. Due to time limitations in sorting samples and the difficulty in distinguishing hardwood fine roots from those of herbaceous plants, hardwood roots in plots with herbaceous vegetation were not sampled. However, sampling was conducted to estimate the distribution of pine roots as affected by herbaceous vegetation. Cores were obtained around three border pine seedlings on herbaceous plots and control plots at distances of 15, 30, 45, 60, and 75 cm from the target seedling. Each core was separated into the same three depth classes used above. Roots were separated from the soil and the biomass of both pine and grass roots was obtained.

Results

Stem volume, live crown volume, seedling height, and root biomass all varied significantly with herbaceous treatment and stand composition (Table 1). In addition, a significant interaction was observed between herbaceous and stand composition treatments for live crown volume, seedling height, and root biomass. Seedling mortality varied little with herbaceous treatment (3 percent for herbaceous control, 4 percent for no control), but differed substantially between individual tree species. Mortality of black locust seedlings averaged 12 percent over all treatments, while loblolly pine and red maple seedling mortality was < 1 percent.

Stands receiving herbaceous control had 2.5x greater stem volume than stands with no herbaceous control (Fig. 1). The presence of herbaceous vegetation appeared to be more detrimental to hardwood seedling yields than pine yields. Seedling heights were reduced 16, 31, and 37 percent for loblolly pine, red maple, and black locust , respectively, in stands with no herbaceous control compared with those receiving herbaceous control (Fig. 2).

Mean stem volume yields due to stand composition varied by 6x from the highest yielding stand type (pure loblolly pine) to the lowest yielding type (pure red maple) (Fig. 3). Yield differences for stand types appeared to be driven by the percentage of pine in the stand and the type of hardwood species. Black locust replacement series attained greater yields than red maple series. Loblolly pine contributed the greatest amount to stem volume yield in all mixtures except one (75 percent black locust, 25 percent loblolly pine). In addition, pines attained greater stem volume yields and heights in mixtures with black locust than in mixtures with red maple when herbaceous control was applied (Table 2). No differences in pine yield due to hardwood species were observed in stands with no herbaceous control. With no herbaceous control, red maple seedlings had significantly greater height, stem volume yield, and live crown volume yield in mixture with loblolly pine compared with red maple monocultures. No other significant difference in yield was observed between seedling growth of any species in mixtures compared with that in pure stands.

Table 1. Probability values for main effects and interactions for stem volume (SV), live crown volume (WV), height (HT), and root biomass (RB) of seedling stands

Effect	SV	Lcv	HT	RB
Block	.0773	.2172	.0001	.5000
Herbaceous treatment	.0022	.0048	.0001	.0600
Stand type	.0001	.0001	.0001	.0700
Herb. x stand	.2092	.0023	.0001	----

Table 2. Mean pine stem volume yield (SV), live crown ratio (LCV), and height (ET) in stands with black locust compared with stands of red maple seedlings. Probability values are given below.

Stand	SV	Lcv	HT
	cm^3	m^3	cm
Black locust	243.1	.60	114.3
Red maple	197.9	.50	105.0
Probability value	.0471	.0309	.0761

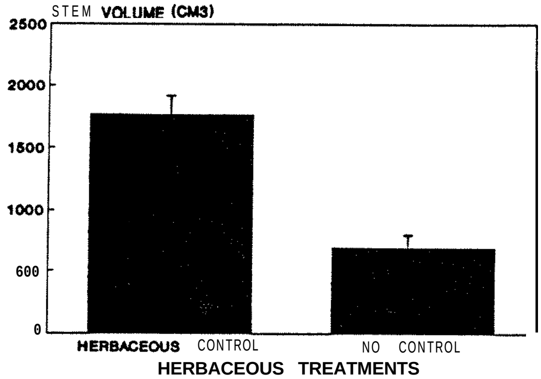

Figure 1. The effect of herbaceous vegetation (fescue) on the mean stem volume yield of 2-year-old pine and hardwood seedlings averaged over all species and stands.

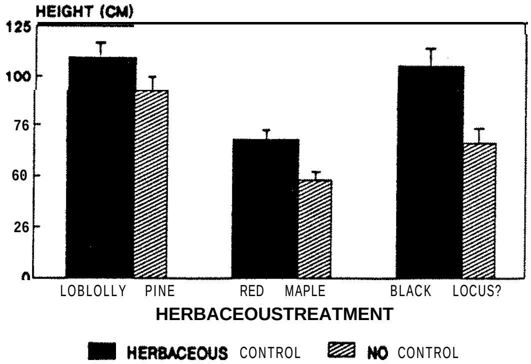

Figure 2. Mean loblolly pine and hardwood seedling heights in stands with herbaceous weed control and with herbaceous vegetation (fescue).

Crown form did not change for red maple and loblolly pine in mixtures vs. monocultures. Pines averaged 100 cm in height and typically possessed a conical or pyramidal shape. Red maples averaged 60 cm in height with an inverse pyramidal shape (Fig. 4). Pine crowns displayed a more elongated form in mixture with black locust than with red maple (Fig. 5). Loblolly pine and black locust attained approximately the same height (110 cm) in mixture. Pines possessed an upright pyramidal or conical crown, while black locust typically had an inverse pyramidal form. The height at largest canopy width increased by 20 cm for loblolly pine and by 10 cm for black locust in pine-locust mixtures compared with pure stands.

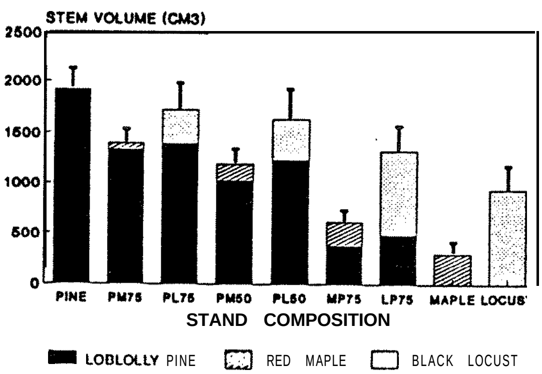

Figure 3. Mean stem volume of species within stands averaged over both herbaceous treatments. For mixed stands, letters indicate the first letter of the common name of pine or hardwood species, and number indicates percentage of that species occurring in the stand. (Example: PM75 indicates a pine-maple stand with 75 percent pine.)

Mean live crown volumes for seedlings in stands with herbaceous control were 2-10x greater than those growing with no herbaceous control (Table 3). Black locust seedlings in pure stands and loblolly pines in mixed stands with herbaceous control had the greatest live crown volumes. However, black locust crowns were reduced considerably more than pine when planted with herbaceous vegetation. Red maple crowns had the smallest live volume, particularly in pure stands.

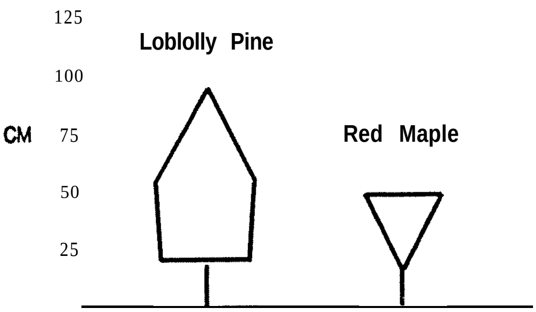

Figure 4. Average crown shape and **dimension** for loblolly pine and red maple seedlings in mixtures on an herbaceous control plot.

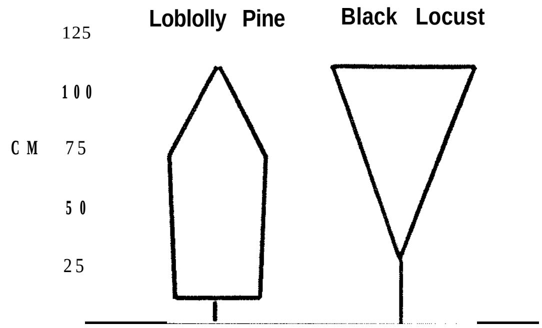

Figure 5. Average crown shape and dimension for loblolly pine and black locust seedlings in mixtures on au herbaceous control plot.

Table 3. Mean live crown volumes and standard errors of stands with and without herbaceous vegetation control.

Stand	Aerbaceous control	No herbaceous control
	cm^3	cm^3
Loblolly pine	0.52 ± .04	0.11 ± .04
Red maple	0.11 ± .02	0.01 ± .002
Black locust	0.88 ± .18	0.10 ± .03
Pine-maple		
pine	0.62 ± .09	0.29 ± .05
maple	0.18 ± .04	0.02 ± .002
Pine-locust		
pine	0.72 ± .14	0.31 ± .05
locust	0.67 ± .10	0.14 ± .04

Table 4. Means and standard errors of root biomass in soil cores from pine and hardvood mixtures and monocultures taken randomly at the midpoint distance between seedling pairs. Pairs in mixed stands included one hardwood and one pine seedling.

Stand	Depth 0-10 cm	Depth 10-20 cm	Depth 20-30 cm
Loblolly pine	.09 ± .05	.10 ± .05	.04 ± .02
Red maple	.06 ± .05	.03 ± .01	.02 ± .02
Black locust	.50 ± .22	.06 ± .02	.06 ± .04
Pine-maple	.21 ± .12	.11 ± .06	.02 ± .02
pine	.14 ± .11	.06 ± .05	.01 ± .01
maple	.O? ± .06	.05 ± .05	.01 ± .01
Pine-locust	.36 ± .09	.12 ± .06	.02 ± .01
pine	.14 ± .03	.01 ± .01	.01 ± .01
locust	.22 ± .08	.11 ± .06	.01 ± .01

Roots of all tree seedlings were concentrated in the surface 10 cm of the soil (Fig. 6). Herbaceous root biomass was also concentrated in the upper 10 cm of soil with 80 percent of all herbaceous roots occurring in this zone. Root biomass of pines in this surface layer was much greater in stands with herbaceous control than in stands with no herbaceous control. However, loblolly pine root biomass in control and herbaceous stands was similar at a depth of 10-30 cm. Pine root biomass decreased in both herbaceous treatments with increasing distance from the central stem (Fig. 7). The total pine root biomass at 15 cm from the stem was 3x as great in stands with herbaceous control compared with no herbaceous control stands. Yet, root biomass at 30, 45, 60, and 75 cm from the stem was similar for the two herbaceous treatments. Black locust seedlings had the greatest root biomass of all species (Table 4). Loblolly pine and red maple trees had greater root biomass in mixed stands compared with pure stands in the surface 10 cm of soil, while black locust root biomass did not differ significantly between pure and mixed stands.

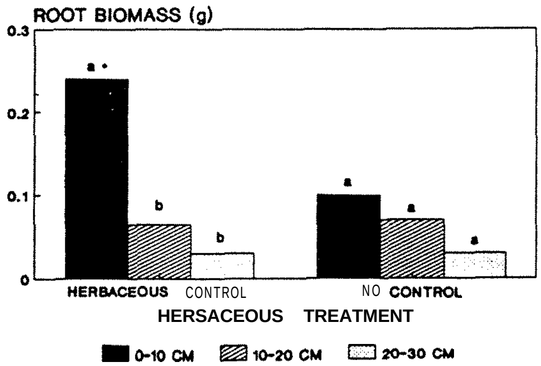

Figure 6. Mean root biomass of loblolly pines to 30-cm depth for herbaceous control and herbaceous vegetation (fescue) treatments. Means with same letter within treatments are not significantly different at p = 0.05; means with asterisk in control treatment are significantly different from the corresponding mean in the vegetation treatment.

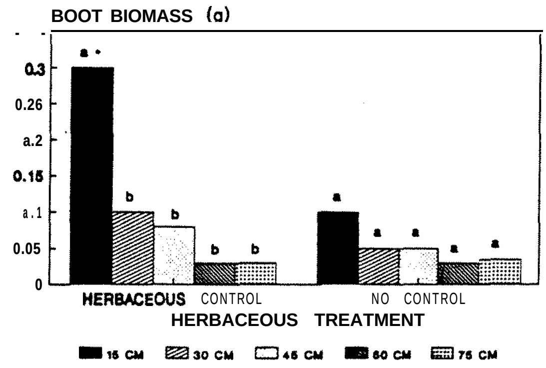

Figure 7. Mean root biomass of loblolly pines with increasing distance from the stem for herbaceous control and herbaceous vegetation (fescue) treatments. Means with same letter within treatments are not significantly different at p = 0.05; means with asterisk in control treatment are significantly different from the corresponding mean in the vegetation treatment.

Discussion

After two growing seasons, patterns of early stand dynamics appear to be driven largely by individual species growth rates and herbaceous competition. However, interference interactions between pine and hardwood seedlings are occurring aboveground in certain stands, and belowground in virtually all stands with herbaceous control.

It is apparent from this study that herbaceous vegetation has an important role in determining the yield and composition of pine and hardwood, stands. Herbaceous vegetation may cause plantation failure (Gjerstad and Barber 1987) or decrease yield on a long-term basis (Glover et al., 1989). The small difference in mortality in stands between herbaceous treatments in the 2nd year of this study is likely due to the herbaceous control treatments applied to all stands during the first growing season. The greater reduction in hardwood compared with pine growth due to herbaceous vegetation implies that the hardwood component of mixed stands should be decreased by silviculturalists unless herbaceous control is an integral part of silvicultural systems.

The high yields of stands composed largely of loblolly pine and black locust are not surprising since these intolerant, early successional species are typified by very rapid initial growth rates (USDA 1965). It is likely that black locust yields would have equaled that of loblolly pine were it not for the greater initial mortality for this species, which appeared to be related to repeated late spring frosts that defoliated many seedlings. Although they have lower initial yields, the more shade-tolerant red maples may eventually be more compatible with the faster-growing pines than would another shade-intolerant species (Smith 1986), such as black locust. A two-tiered stand would develop with the intolerant species (loblolly pine) in the overstory and the more shade-tolerant species (red maple) in the understory. The pine could then be harvested earlier, releasing the red maple to grow for a future harvest. Unlike red maple, however, black locust may benefit pine growth through nitrogen fixation or higher quality litter inputs (Boring and Swank 1984).

The lack of difference in growth for species in pure vs. mixed stands may be attributable to the young age of the stand in which intra- and interspecific interactions have only begun to occur. However, pine yield did vary with its hardwood associate, having greater aboveground yield with black locust than with red maple. The mechanism for this difference is unclear. Having greater biomass and height, black locust would likely reduce pine yield more through resource competition than would red maple. Nodules were present on black locust roots excavated in this study. However, potential addition of nitrogen from nitrogen fixation by black locust should be small after only two growing seasons. In addition, the demand for nitrogen by pine at this point in the rotation is likely to be small and the soil supply large (Allen et al., 1990). It should be noted, however, that loblolly pine and black locust crowns have begun to interact, while red maple and loblolly pine crowns have not. It is possible that partial shading may have reduced temperature extremes during the growing season, which led to decreased respiration and increased yield for pines in mixtures with black locust compared with red maple. It is also possible that loblolly pine is allocating more resources aboveground in stands with black locust as a response to this increased shading. However, the decline in belowground growth for pines in mixtures with black locust compared with those growing with red maple is not substantial (Table 4). The greater red maple yields with loblolly pine and herbaceous vegetation as compared with pure red maple with herbaceous vegetation may be due to some suppression of herbaceous vegetation by pines.

Differences in crown form between species may be one determining factor in competition outcomes in mixed stands. The conical, excurrent crown form of pines along with a high live crown ratio allows for rapid height growth (Zedaker et al., 1987) and increases the percentage of the crown receiving full solar radiation. Yet, this upright, pyramidal form may be easily shaded by the inverse pyramidal form of black locust seedlings (Fig. 5). Crown form, however, can plastically respond to aboveground competition, exemplified by the shift in height at greatest crown width for pine and black locust seedlings in mixed stands compared with pure stands with herbaceous control. The ability of a species to plastically respond to crown competition is likely to be an important determinant in competition outcomes (Hutchings and Budd 1981; Grime et al., 1986). The final analysis of this plastic response can only be made after crown closure. It is likely that spacing and proportions of pines and hardwoods in mixtures will be critical to optimizing the effects of differences and plastic response in crown form.

Data on root biomass and distribution in forest stands are always difficult to obtain and interpret. The high variability in seedling root biomass data in this study is indicative of the problems with root sampling. Yet, while random and sampling variability is high, it is still fairly evident that most of the interactions between seedlings belowground are occurring in the surface 10 cm of soil. The strength of the herbaceous effect can be attributed to the large biomass of herbaceous roots occupying this zone which is also important for moisture and nutrient uptake by tree species. Root biomass at greater soil depths appears to be unaffected by herbaceous vegetation.

Black locust roots had greater lateral root biomass than other stands. However, this larger lateral biomass may be offset by reduced taproot biomass, which was not quantitatively sampled in this study. Al though black locust seedlings displayed a pronounced taproot form at time of planting, seedlings recently excavated in the study appeared to possess a more extensive laterally-distributed root system than did loblolly pine or red maple seedlings. This extensive lateral root system, containing a large amount of absorbing surface may explain the capability of black locust seedlings to attain rapid initial growth. The mechanism of greater root biomass of red maple and loblolly pine seedlings in mixtures compared with pure stands is unknown. It is possible that there may be an increased shift in root allocation for these two species due to interspecific competition (Caldwell 1987, Feldman 1988). However, it should be noted that belowground productivity and interactions may not be explained by estimates of root biomass if turnover rates of roots differ with species and/or stands in this experiment (Caldwell 1987).

Conclusions

The growth of pure and mixed stands of pines and hardwoods after 2 years in this study can be explained largely by individual species growth rates and competitive interactions with herbaceous vegetation. However, interactions among seedlings in these stands have already begun to occur both above- and belowground, and appear to be affecting seedling yield and form. A continuing assessment of yields and competitive relationships will be made in subsequent growing seasons as interference interactions within stands accelerate. Investigations of physiological mechanisms, which may help explain competition outcomes will also be conducted, to include light availability within stands, photosynthetic rates of species, seedling water potentials, and seedling and soil nutrient concentrations.

Acknowledgments

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FATE AND TRANSPORT OF FORESTRY HERBICIDES IN THE SOUTH: RESEARCH KNOWLEDGE AND NEEDS [1]

Jerry L. Michael and Daniel G. Neary [2]

Abstract. A review of the fate and environmental risks associated with the use of hexazinone, imazapyr, sulfometuron methyl, and triclopyr in pine silviculture in the South is presented. Herbicides used in forestry can contaminate surface waters to varying degrees depending on the application rate, method of application, product formulation, and site specific characteristics, but streamside management zones (SMZ) greatly reduce stream contamination. Highest concentrations measured in streams occurred in short duration pulses during the first two or three storm events following application. Stream contamination usually declined rapidly thereafter. The highest concentrations of herbicides observed in streams are usually lower than concentrations determined to be safe by the Environmental Protection Agency's Office of Drinking Water for domestic drinking water. Persistence of herbicides on treated sites is affected by many factors. Half-life in vegetation is ususally < 40 days and from 7-180 days in soil. Environmental Impact Statements and Risk Assessments completed for the southen United States concluded that: (1) no member of the public, including sensitive individuals, should be affected by typical exposures to herbicides or associated chemicals used for vegetation management in the South; (2) the risk of dying or from cancer is greater after drinking 40 diet sodas with saccharin, consuming a total of 2.7 kg (6 lb) of peanut butter, drinking 750 L (200 gal) of water from Miami or New Orleans, or smoking two cigarettes than it is from exposure to herbicides used in the South, even for workers; and (3) care needs to be taken with herbicides concerning threatened and endangered species. More research is needed for new herbicides because: (1) analytical problems are greater for new herbicides which are used at very low rates and biodegrade rapidly; (2) new herbicides should be screened for toxicity against threatened and endangered plant species; and (3) research should define the role of SMZs in reducing stream contamination so that SMZ size can be prescribed on a site specific basis.

Introduction

There are many issues surrounding use of herbicides in forestry and most of these seem to have arisen from an association with agricultural food crop uses. The distinction between intensive forest management use of herbicides and agricultural is significant, but seldom presented. While agricul-

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tural uses involve multiple applications annually of pesticides on most units of land in use, intensive forest management practices seldom utilize herbicide applications more than twice (site preparation treatment and a release treatment) within a 30- to 80-year rotation cycle (Michael et al,, 1990). In the South, herbaceous weed control in the year of planting often precludes the need of a second application for release, resulting in a single application over a 30- to 80-year cycle (Nelson et al., 1985; Michael 1985). Use of herbicides in intensive forest management, then, means that even if every forest site is intensively managed, the risk to the public and the environment is less than one-thirtieth that in food crops. However, the decreased frequency of occurence of concerns does not render them irrelevant.

A National Forest Environmental Impact Statement (EIS) (USDA Forest Service 1989a) provides some insight into the concerns of citizens when management of public forest land is considered. Nearly 900 respondents in 28 states volunteered comments on issues concerning management of this resource. Similar information is not available for industrial lands, but it is instructive to consider the issues brought forth in the EIS. Respondents' comments were categorized according to several broad issues. As may be expected, a major issue dealt with whether National Forest land should be managed regardless of the tools used. Concerns under this broad issue are: (1) too much emphasis on timber production; (2) impacts of forest management on wildlife and plant diversity; (3) impacts on visual and cultural (artifacts) resources; and (4) concern over the impacts of changes in forest management practices on management costs and on employment at the local level. Issues that dealt specifically with herbicides were: (1) risks to humans and the environment from aerial application; (2) human health and safety; (3) impacts on plant communities, especially threatened, endangered, and sensitive species; and (4) impacts on soil productivity and water quality. These issues are worthy of consideration regardless of the frequency of occurence. Research has addressed issues 1, 2, and 4 through monitoring studies and risk assessment. This paper presents a brief summary of current research data relative to these topics.

Environmental Fate

Herbicide persistence and contamination of the various environmental matrices related to human health and safety, soil productivity, and water quality have been the subject of monitoring studies in the South. Except for the phenoxy herbicides, the most often used herbicides have been around for approximately 10-15 years. Phenoxy herbicides have been the subject of very intensive study for several decades and are not covered in this paper. Persistence, described in terms of half-life, determines the length of time over which exposure and therefore direct adverse impacts can occur.

Half-life

The most often used term in describing herbicide persistence is half-life. Generally herbicide disappearance from a site approximates a logarithmic decay curve similar to that of a first-order chemical reaction. Transformation of dissipation data permits graphic representation:

$$\mathrm{Log}_{10}\ \text{Tissue Concentration vs. Time.}$$

Simple linear regression of transformed data yields an equation of the form:

$$\text{Log } Y = aX + b,$$

from which the half-life is calculated as the time at which half of the regression maximum concentration (X = Time = 0) has dissappeared. The slope (a) or rate of dissipation is very dependent on the maximum concentration observed in the field and on the timing, rate, and duration of the first precipitation event following application. For volatile chemicals, the rate of dissipation also depends on the temperature and wind conditions immediately following application. While recognizing the weakness of the "half-life" term, we will use it for lack of a better one.

Cycling

One of the main reasons for the weakness of the half-life term is "cycling." Herbicides may move or cycle from one matrix to another and back via physical and biological routes. The movement of sulfometuron methyl from plant tissue to litter resulting in a maximum observed litter concentration 3 days after treatment, and from litter into soil resulting in a maximum observed soil concentration 7 days after treatment, has been noted following very small precipitation events (Fig. 1) (Michael and Neary 1987). Similar transfers have been observed for hexazinone (Michael and Neary 1990).

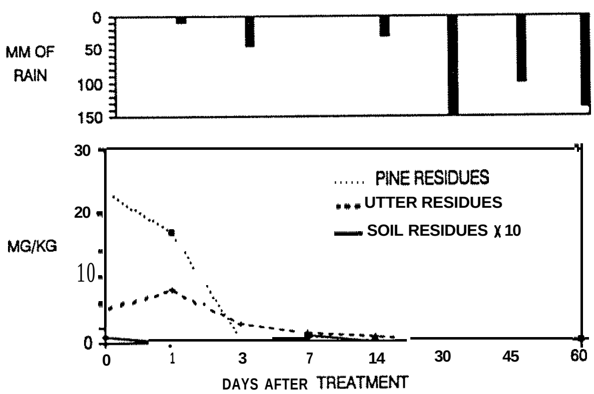

Figure 1. The transfer of sulfometuron from vegetation to litter, and then to soil.

Plants

Herbicide persistence in plants may vary considerably depending on the species, applied rate, and environmental conditions (Table 1). Values reported here are those observed under actual field conditions. Typically, the highest observed concentrations are in the low parts per million range, even for vegetation treated with rates in < 300 g/ha range. Cycling of herbicide from plants to litter to soil and back again to the vegetation has been demonstrated for some herbicides. Sulfometuron methyl cycling is demonstrated in Figure 1. Uptake from soil occurred, following precipitation, within 3 days after treatment, and resulted in observable increases in tissue concentrations by 7 days after treatment.

Soil

Cycling also affects soil concentrations. It can affect the shape of the dissipation curve by causing higher concentrations several days after treatment than observed on the day of treatment (Fig. 1). In addition to

Table 1. Herbicide persistence in plants under field conditions.

Herbicide	Applied rate	Half-life	Plant species
	(kg ha^{-1})	(days)	(number)
Hexazinone	1.7	4-15[a]	5
Imazapyr	2.2	12-40[b]	(composited)
Sulfometuron methyl	0.4	1-12[c]	9
Triclopyr	4.5	< 7[d]	(grasses)

[a] Michael and Neary 1990.
[b] Michael 1986.
[c] Michael and Neary 1987.
[d] Bush et al., 1988.

attenuating the dissipation curve, cycling causes a worse fit (decreased R^2). Half-lives of herbicides under field conditions are highly variable and may be more affected by initial application rates and occurrence of precipitation than by biological activity, but they do indicate trends in persistence (Table 2). Thus laboratory studies of biological activity under controlled conditions must also be considered in determining the environmental fate of herbicides.

Table 2. Herbicide persistence in forest soils following application for vegetation management.

Herbicide	Applied rate	Half-life
	(kg ha^{-1})	(days)
Hexazinone	1.7-2.9	21-180[a,b,c]
Imazapyr	2.2	19-34[d]
Sulfometuron methyl	0.4	7-26[e]
Triclopyr	4.5	10-46[f]

[a] J.L. Michael, unpublished data.
[b] Bouchard et al., 1985.
[c] Michael and Neary 1990.
[d] Michael 1986.
[e] Michael and Neary 1987.
[f] Bush et al., 1988.

Water

Movement of herbicides through the various site matrices (water, soil, and vegetation) is governed by the relative presence or absence of water. Because all forest herbicides are water soluble to some extent, either by nature or by virtue of the way they are formulated, the water cycle governs their disappearance. This is true whether it is by the more obvious routes of evaporation, runoff, and leaching, or by the less obvious routes of plant uptake, metabolism, hydrolysis, and in some cases even photolysis.

There are two major routes of herbicide entry into streams. The first is direct application and the second is through stormflow. Less important are interflow (water movement in the saturated and unsaturated portions of the soil profile) and underflow (movement of water under stream beds). Direct application is responsible for the most severe stream contamination (Table 3), and is the easiest

Table 3. Maximum observed concentrations of herbicides in surface water from environmental fate studies in the southern United States.

Herbicide	Applied rate	SMZ[a]	Concentration	Number of studies
	(kg ha^{-1})		(µg L^{-1})	
Hexazinone	1.7-2.9	Yes	ND-37	9[b,c,d]
	0.8-1.7	No	442-2400	2[e,f]
Imazapyr	2.0	Yes	130	1[G]
	2.0	No	680	1[G]
Picloram	0.3-5.0	Yes	ND-21	7[b]
	5.6	No	241	1[h]
Sulfometuron methyl	0.4	Yes	7-44	2[i]
Triclopyr	4.5	Yes	2	1[j]

[a] Streamside Management Zone.
[b] J.L. Michael, unpublished data.
[c] Bouchard et al., 1985.
[d] Michael and Neary 1990.
[e] Neary et al., 1986.
[f] Miller and Bace 1980.
[g] Michael 1986.
[h] Michael et al., 1989.
[i] Michael and Near-y 1987.
[j] Bush et al., 1988.

to control. It includes direct application to active streams and dry stream channels. Another and less obvious path of direct insertion into streams is throughfall. In this process, vegetation which overhangs streams and stream channels is impacted with herbicide spray. Subsequent drippage or runoff from foliage and stems can fall directly into streams. Additionally, a heavy dew (as often occurs during spring application window) or storm event can result in washoff of herbicide which has not been completely absorbed. This washoff can also fall directly into streams. When throughfall or washoff falls into previously dry stream beds it is in place to be moved into perennial streams by stormflow.

Stormflow is the path by which most post-application stream contamination occurs. Research has shown that approximately 90 percent of all herbicide leaving a site and contaminating a stream reaches that stream during the first two to three storm events following application. The longer the period between application and the first storm event, the less severe is stream contamination. Stormflow is made up of several components but especially important is the contribution of flow over previously dry areas. These include ephemeral stream channels, and overland flow across the landscape surface. When large storm events occur, much water may be deposited in small to large channels which are drainage channels but are usually dry. They can be recognized in the field by scouring of the soil surface (landscape incision) and often by the deposits of litter and sticks left by receding stormflow from earlier events. Overland flow is that flow of water over the surface of soil that has never infiltrated the soil surface. The rate of precipitation required to initiate overland flow is based on the soil type, surface characteristics, (i.e., whether it is covered by litter, vegetation, or is bare and whether it is disturbed or undisturbed), and rainfall intensity. Generally speaking, the infiltration rate of bare clay textured forest soils ranges from 0 to 5 mm of water per hour while that for the same soil covered by vegetation is 5 to 10 mm/hr. When the rate at which rain is falling exceeds the infiltration rate, there will be overland flow. Thus when the rate of rainfall on some of typical Piedmont soils in the South exceeds 5 mm/hr for bare ground and 10 mm/hr for vegetation covered soil, there is a distinct probability of overland flow. On many well-developed and undisturbed forest soils, infiltration rates always exceed maximum rainfall intensities. The distance over which overland flow occurs varies widely, but it must be accepted that when overland flow reaches a drainage channel of any size it will contribute to the overall level of stream contamination.

Maximum observed concentrations of herbicides in water from treated areas varies depending on a number of factors including the application method, the applied rate, and the existence of a streamside management zone (SMZ), or an untreated buffer zone. The U.S. Environmental Protection Agency (EPA) has established a "Safe Drinking Water Level" of 200 µg/L (parts per billion) for hexazinone (U.S. EPA 1989). Use of an SMZ typically maintains even the maximum observed water concentrations well below this level (Table 3). These maximum observed levels are ephemeral, often lasting less than 15 minutes and are well below observed toxic levels for most southern aquatic species. Use of a streamside management zone is the most easily controlled factor in reducing surface water contamination. While SMZs do not have to be large to be effective, little is known about their exact role in mitigating stream contamination. Obviously maintenance of an SMZ greatly reduces the amount of direct stream input, but the attenuating effects on stormflow and baseflow inputs has not been defined.

Risk Assessment

The U.S. Forest Service has intensively analyzed the environmental impacts of herbicide use for vegetation management on National Forest System lands in the South. The result of this analysis has been publication of EISs for the geographical areas where herbicide use is proposed (USDA Forest Service 1989a, 1989b, 1990). One component of the EIS is a Risk Assessment which deals specifically with human health and safety.

There are three major components to a Risk Assessment. The first is a Hazard Analysis. In the Hazard Analysis, published data and publicly available summaries of proprietary data were reviewed concerning the hazardous properties of individual herbicides. The review considered acute, subchronic and chronic toxicity effects for all major routes of exposure. It also determined threshold toxicity values for LD_{50}s, systemic and reproductive no-observable-effect-levels, carcinogenicty, and mutagenicity for each herbicide.

The second component, Exposure Analysis, estimated single and multiple exposures for workers and members of the public likely to be exposed. Three exposure scenarios were developed. The "typical" scenario considered exposures likely to occur during application, the "maximum" scenario estimated the maximum exposure likely to occur in the absence of an accident, and the "accident" scenario estimated direct exposure from concentrated herbicide, spray mix, and spills.

The third component, Risk Analysis, combines the hazard analysis, the exposure analysis for various scenarios, and the probability that exposure could occur to predict health effects on indivivuals. This last step also considers common risks from alternative vegetation control measures. Where valid human studies existed, a tenfold safety factor was applied if there was no indication of carcinogenicity. If no human studies were available, but long-term animal studies existed, a safety factor of 100 was built into the analysis. In cases where there were no long term animal studies and toxicological data were limited, a safety factor of 1000 was built into the risk analysis.

The Risk Analysis (USDA Forest Service 1989a) concluded that no member of the public, including sensitive individuals, should be affected by typical exposures to herbicides or associated chemicals used for vegetation management in the South. Workers were found to be at greatest risk, but even workers are subject to less than one in a million chance of adverse health effects except for the accident scenario in which workers did not wash spilled herbicide off their bodies. Even in this extreme case, lifetime cancer risks were less than one in a million for all of the 14 chemicals considered except 2,4-D. By comparison, the probability of death or cancer for all individuals is one in a million over a lifetime from: (1) drinking 40 diet sodas with saccharin; (2) consuming a total of 2.7 kg (6 lb) of peanut butter; (3) drinking 750 L (200 gal) of water from Miami or New Orleans; or (4) smoking two cigarettes (USDA Forest Service 1989a).

Research Needs

While we know much more now about the fate of herbicides in southern forest ecosystems and public and worker risk than we did 15 years ago, there is still much to be learned. New chemicals are continually being developed that are effective at lower and lower rates. The newest herbicides belong to a class of compounds known as acetolactate synthase (ALS) inhibitors (Moberg and Cross 1990). Acetolactate synthase inhibitors include the sulfonyl ureas, triazolo-pyrimidines, and imdiazolinones. These compounds inhibit the synthesis of branched-chain amino acids (valine, leucine, and isoleucine) considered to be essential to mammals, but which mammals cannot synthesize. Because mammals lack the ability to synthesize branched-chain amino acids, the mode of action of these herbicides is inherently selective for plants. Many of these new compounds are very short-lived in the forest environment, i.e., sulfometuron methyl has a hydrolytic half-life of about 20 days at pH 5. New compounds may or may not behave similarly to existing herbicides and research will be needed to determine their persistence and potential for adverse site effects.

The new chemicals--along with most existing forestry herbicides--are water soluble and so their movement into water should be guarded against. More research is needed to provide a sound basis for mitigation techniques in water quality protection. In addition there is a trend toward development of herbicides effective at extremely low application rates. This means they are phytotoxic at extremely low concentrations, possibly below our current detection levels. Detection limits currently are around 1 µg/L (ppb) for herbicides in very clean samples like stream water and around 20 to 50 µg/L for other samples like soil and plant tissue. Phytotoxicity of the newest herbicides may occur below 1 µg/L for some aquatic plant species. Environmental fate studies are complicated by this level of activity because accidental significant cross-contamination of samples is much easier and because the chemical analysis becomes much more difficult. In order for impacts on aquatic ecosystem form and function to be assessed, new and more sensitive analytical techniques must be developed. Methods using the enzyme-linked immunosorbent assay (ELISA) afford quantitation at extremely low levels of contamination and provide a new approach to this most difficult of analytical problems.

Threatened and endangered (T&E) species are assumed to be adversely affected by forestry herbicides, but that is not necessarily correct. There are many plant species resistant to herbicides and it may be that some T&E species are also resistant. A screening program could identify T&E species which have been focal points in forest management, particularly those located in the coastal plain pine growing regions. Identification of herbicide resistance in these species could save herbicides as forest management tools for some areas previously slated for exclusion.

St reamside management zones have been mentioned several times as a way of reducing contamination of streams with herbicides. There is proof that they work, but not much is known about site-specific design of SMZs. Research needs to define the conditions and parameters under which SMZs are effective.

Challenges to Management

A statement often heard is, "We never do that." During one study, the pilot was instructed to shut-off application over streams carrying water and to side dress those buffers. After the application one of the land managers came up and said, "Why did you do that?" the answer was simply, "The label says so." Logan Norris, Oregon State University, and former Project Leader with the Pacific Northwest Forest and Range Experiment Station, said it well when he said, "If you don't want it in the water, don't put it there." It is not clear what size SMZ is optimal, but any SMZ helps keep herbicides out of surface waters. The challenge to forest management is to so instill in their employees caution when it comes to herbicide application that when they go to a site and tell the applicators to keep it out of the water, everyone will respond, "We always do that." In the years ahead, forestry will always have to justify its professional position on the use of pesticides, but with sound management practices, based on research results, there will be a future.

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USE OF COMPUTER MODELS TO EVALUATE POTENTIAL HERBICIDE RUNOFF FROM SILVICULTURAL OPERATIONS [1]

Parshall B. Bush, Daniel G. Neary, John W. Taylor, and John G. Dowd [2]

Abstract. The increased use of herbicides in forestry throughout the South in the past decade has generated a need for tools to assess the environmental fate and impacts of these chemicals in forested watersheds. A variety of environmental simulation models, ranging from simple empirical ones to complex process models, have been developed for determining the effects of intensive forestry on soil and water resources. The most complex models include AGNPS, ANSWERS, CMLS, CREAMS, EPIC, GLEAMS, LEACHMP, PRZM, QUAL II, SEDIMOT, SPUR, SWRRB, USLE, and WEPP. However, only CMLS, CREAMS, GLEAMS, LEACHMP, PRZM, and QUAL II simulate herbicide movement. Important aspects to be considered in the use of these simulation models are: (1) an understanding of real ecosystem functioning; (2) model validation; (3) spatial scale; (4) accuracy needs; (5) computing resources; and (6) model application. Validations run on actual monitoring data for hexazinone (CREAMS) and picloram (PRZM) indicate close approximation of herbicide movement once the hydrologic simulation matches site conditions. These models are very useful in selecting among alternative herbicides based on environmental considerations and in guiding the development of monitoring plans.

Introduction

An important aspect of forest management decision making is the determination of potential impacts of silvicultural operations on non-timber resources such as water and soils. Water is an important by-product of forest lands (Anderson et al., 1976) since many surface waters which originate in forests are used for municipal and domestic water supplies. Also, many key ground-water recharge zones are forested. Degradation of surface and ground-water quality in agricultural and urban land-use areas from nonpoint source pollution has placed a high priority on maintaining the quality of water in forested watersheds.

Intensive forestry practiced in the South has traditionally used techniques such as burning and mechanical site preparation. Herbicide application increased rapidly in the past decade due to the high economic and environmental costs of mechanical site preparation, the increased availability of effective and selective forestry herbicides, improved herbicide application systems, concerns about smoke production from prescribed fires, and the

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need to ensure adequate survival of plantations where weed growth is vigorous. However, there has been a great deal of national concern about pesticide contamination of surface and groundwater. Although research has indicated that forestry's use of herbicides poses a very low risk to water quality' (Neary 1985; Neary et al., 1986; Near-y **1988),** chemical weed control on forest lands has remained controversial. It is obvious that forest managers cannot afford to monitor in detail the effects of every herbicide application on every site. Thus, environmental simulation models can provide scientifically-based tools for estimating the impacts of herbicides over relatively large landscapes.

Models which can simulate the environmental effects of land management practices such as herbicide application are simplifications of complex real processes. However, these models can improve understanding of actual biological and physical systems as well as aid the planning of management activities (DeCoursey 1985, Foster 1987). Many factors, alone or in combinations, can be analyzed in short time frames which would be impossible under actual conditions. These models provide the equivalent to economic forecast models and thus can introduce environmental considerations into the land management process.

Model development has gone through two stages. First, most early models were empirical, or "black box" models. These required large amounts of data but consisted of regressions between data of observed responses to imposed treatments. Many of these were site specific, but some were regional in nature when they included large amounts of data and a wide range of treatments, sites, and effects. Eventually these models and additional research led to an understanding of the processes which went on inside the "black box." The development of improved computing systems and understanding of individual processes resulted in the more sophisticated process models. These models are more useful since their accuracy is tied to the representation of an actual landscape process and not to the amount of data and the range of conditions previously measured.

There are four stages in the development of empirical or process-based environmental simulation models. First, an understanding of the biophysical system and its component processes is required. Secondly, experimental data are required to develop mathematical expressions that represent system functions. Technically, a model is constructed after this step although a conceptual framework is needed beforehand. Thirdly, a model must be validated with a set of data independent from the data used to construct the model. Fourth, modifications are made based on the validation. Steps three and four are key parts of the development process and are repeated to improve simulations.

Another consideration in both model development and management applications is the question of landscape scale. Environmental simulation models can operate on scales of a plot, hillside, small watershed, or large watershed. As scale increases, the complexities of the physical and biological system increase. Model complexity, computer requirements, and error increase accordingly. Model users must be aware of these problems when applying models to real situations and interpreting simulation results.

Table 1. Environmental simulation models for estimating herbicide movement.

A. Characteristics					B. References	
Model	Type	Scale	Erosion	Time frame	Model	Reference
CMLS	Process	Plot	No	Continuous	CMLS	Nofziger and Hornsby 1984
CREWS	Process	Plot	Yes	Continuous	CREAMS	Knisel 1980
GLEAMS	Process	Plot	Yes	Continuous	GLEAMS	Leonard et al., 1987
LEACHMP	Process	Plot	No	Continuous	LRACHMP	Wagenet and Hutson 1986
PRZM	Process	Plot	No	Continuous	PRZM	Carsel et al., 1984
QUAL II	Process	Watershed	Yes	Continuous	QUAL II	Roesner 1977

Two other aspects of environmental simulation models must be considered. These are the accuracy needed and the computing resources available for simulation efforts.

A variety of models have been developed to simulate the environmental impacts of land management practices. These include AGNPS, ANSWERS, CMLS, CRRAMS, EPIC, GLRAMS, HSPF, LEACHMP, PRZM, QUAL II, SEDIMOT, SPUR, SWAM, SWRRB, USLE, and WEPP. Of these, only CREAMS, CMLS, GLRAMS, LRACHMP, PRZM, and QUAL II simulate herbicide movement (Table 1). Most were originally developed for agricultural situations and have been adapted or modified for forestry conditions.

To understand herbicide movement within and out of a watershed, water movement must be understood since it is the principal vector for herbicides in ecosys tems. There are three major flow pathways in watersheds: (1) overland flow; (2) subsurface saturated and unsaturated laminar flow (Darcian flow); and (3) subsurface turbulent macropore flow. One of the major problems in adapting agriculture-based simulation models is that overland flow, a major component in agricultural watersheds, rarely occurs in well-developed forest soils. In addition, subsurface macropore flow commonly occurs in forested watersheds but not agricultural ones, and is difficult to model.

The objective of this paper is to examine several simulations for applications of forestry herbicides. One of these is an unvalidated simulation that was run to guide monitoring.

Methods

CRRAMS Simulation Model

The CRRAMS (Chemicals, Runoff , and Erosion in Agricultural Management Systems) model is composed of a series of submodels linked together to produce an integrated estimate of stormflow, infiltration, erosion, and dissolved and adsorbed plant nutrients and pesticides (Knisel 1980). The hydrology submodel drives the other submodels, and provides the transport medium for chemicals and sediments. Daily precipitation totals are required, and stormflow is predicted using the Soil Conservation Service runoff curve number method. Required input data to the hydrology submodel in addition to rainfall are mean monthly temperature and radiation, watershed physical parameters, and soil hydraulic properties.

The pesticide submodel of CREAMS allows specification of different decay rates for chemical residues on the soil. Movement of pesticide below the soil surface is estimated for highly soluble chemicals, but vertical and lateral movement at greater depths over time are not directly simulated. Concentrations of herbicide in solution and adsorbed onto sediments, as well as the mass transported by each process, are calculated. Pesticide residues remaining in the soil surface and total pesticide lost are calculated after each storm is simulated.

The GLEAMS model was developed as an extension of CREAMS to consider vertical fluxes and simulations of pesticide subsurface movement (Leonard et al. , 1987). Modifications of the basic CREAMS model to improve the accuracy of simulations in forested watersheds have been incorporated into GLEANS (Nutter et al., in press). Validations of GLEAMS using data sets from forestry applications of herbicides are currently in progress (Smith et al., 1991).

PRZM Simulation Model

PRZM (Pesticide Root Zone Model) is a dynamic compartment model for use in simulating chemical movement in unsaturated soils within and below the plant root zone (Carsel et al., 1984). Time varying herbicide transport is represented by a finite difference solution to the advection/dispersion equation. Like CREAMS, the hydrology submodel is the simulation driver. PRZM uses daily rainfall and temperature data, open pan evaporation, watershed physical parameters, and soil hydraulic properties. Individual parameters are described in greater detail by Carsel et al. (1984). The hydrology component for calculating runoff and erosion is based on the same method as CREAMS.

Soil and chemical parameters affecting persistence and transport of the pesticide being simulated complete the basic data inputs. Studies comparing PRZM predictions with measured values (Bush et al., 1986) have shown that adsorption coefficient (Kd), soil organic matter content by horizon, and half-life (Ks) are key parameters.

CREAMS Validation - Hexazinone

This study site was located in the upper Piedmont of north Georgia within the drainage of the Broad River. A complete site description is given by Neary et al. (1983). The site contained a low-quality mixed hardwood stand. Soils were predominantly sandy loam Kandic Hapludults of the Cecil Series. Five watersheds, 0.8 to 1.1 ha in size, were instrumented with h-flumes and water samplers. Stormflow samples were collected from 26 runoff events from April 1979 to 27 May 1980. Hexazinone in a pellet formulation was applied by hand at a rate of 1.68 kg ai/ha in late April 1979. Simulation details are given in Nutter et al. (1984).

PRZM Monitoring Evaluation - Hexazinone

This site is located near Smith Peak in the Stanislaus National Forest of east-central California within the drainage basin of Jordan Creek. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws var. *ponderosa*) and various oak species (Quercus sp.) occupied the site until a wildfire struck in late 1987. Following the fire, the stand was seeded into rye, but natural succession has resulted in establishment of a number of herbaceous and woody pioneer species. The soils are shallow-to-moderately deep Lithic Xerochrepts on steep slopes. Simulations were run for wet conditions typical of 1978-1979 instead on actual rainfall to analyze potential movement under high hazard conditions. PRZM simulations were run for applications of hexazinone liquid and/or granules at a rate of 1.0 kg ai/ha on the first day of December, February, April, and June, 1987.

Results And Discussion

CREAMS Validation - Hexazinone

The results for the CREAMS simulation of the hexazinone application and its comparison with the field measurements are shown in Figure 1. As expected, the stormflow events with the highest hexazinone concentrations were those closest to the application date. The predicted concentrations decreased over time until 150 days after application, when only small amounts of hexazinone (< 0.01 µg/L) were predicted in stormflow. The predicted and measured concentrations were similar for the first 75 days. However, between 75 and 270 days the measured herbicide concentrations remained elevated at 10 to 20 µg/L. In the next stormflow event after 270 days (at 320 days), the herbicide was not detectable.

Predicted and actual hexazinone concentrations in the stormflow are in close agreement for events occurring 0 to 75 days after application. For storms occurring more than 75 days after application, the model consistently underpredicts hexazinone concentrations in stormflow. The inability to predict hexazinone concentrations after 50 to 75 days may be due to a change in the source of the hexazinone to stormflow.

The source area for s tormflow is the ephemeral stream channel and the immediate surrounding area. This is the only portion of the watershed where overland flow is likely to occur. The model predicts the declining hexazinone availability in the source area, but cannot include the addition from the delayed upslope subsurface flow. Because this version of CREAMS model does not account for movement of herbicide within the soil, it would not predict the continual supply of herbicide to the channel region from interflow.

CREAMS simulations, run for a 50-year period of record using the daily rainfall hydrology submodel, show that of the five herbicides tested, bromacil, hexazinone, and triclopyr have the greatest potential for movement in stormflow from the forested Piedmont watersheds (Fig. 2). Bromacil concentrations declined the least as the recurrence interval decreased. This results from bromacil's tendency to bind to clay and organic matter colloids (high partitioning ratio, Kd = 10), hence its long persistence time in the soil surface zone. The concentration of bromacil simulated in s tormflow can be expected to be greater than 1000 µg/L at least once every 8 years (12 pereent probability of occurrence). In contrast, simulated concentrations of picloram and dicamba (Kd < 1) do not exceed 30 µg/L (Fig. 2). Thus, bromacil and triclopyr, with high Kd values and moderate-to-low solubilities, and hexazinone with a high solubility and moderate Kd value, produced greatest concentrations in runoff.

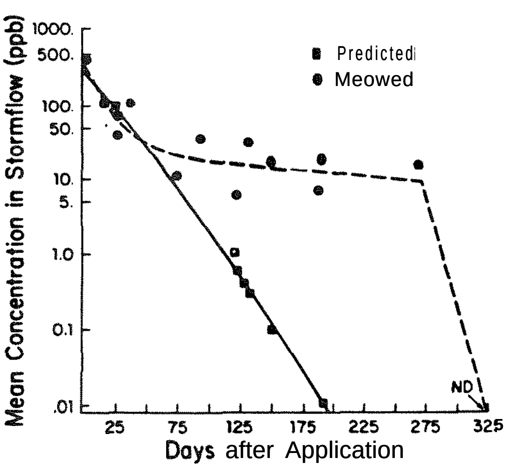

Figure 1. Mean predicted and actual hexazinone concentrations in stormflow as a **function of time after application (after Nutter et al.,** 1984).

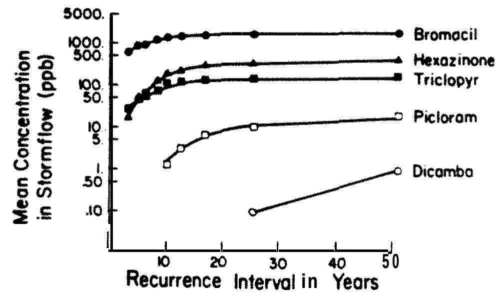

Figure 2. Reoccurrence intervals of maximum annual concentrations for various pelleted herbicide applications on 1 May of each year, as predicted from 50 years of stormflow and herbicide concentration simulations by CREAMS (after Nutter et al., 1984).

The low predicted storm runoff concentrations at Kd < 1 (picloram and dicamba) can be attributed to reduction surface concentrations of pesticide due to leaching prior to stormflow. Because the partitioning ratio reflects the tendency to absorb to clay and organic matter colloids, a low Kd means a pesticide has only a weak tendency to bind to colloids. Both herbicides have negative charges and have only a weak tendency to bind to colloids in the acid soil. As a result, they leach out of the surface soil horizon. Before CREAMS calculates the pesticide available for extraction to stormflow, the amount of pesticide available is reduced by the vertical movement of pesticide out of the surface zone in the percolate. The amount removed in this way is mainly a function of Kd. Thus, herbicides with low partitioning ratios such as picloram (Kd = 0.7) and dicamba (Kd = 0.077), will not be available in the surface zone for extraction to stormflow.

PRZM Monitoring Evaluation - Hexazinone

For the California watershed, application dates of 1 December 1986, 1 February 1987, 1 April 1987, and 1 June 1987 were simulated. The deeper soils nearer to riparian areas were used to determine the effect of hexazinone application date on the predicted groundwater (stream baseflow) and storm runoff concentrations (Fig. 3). Application of hexazinone in December or February (the periods of heavy precipitation and low evapotranspiration) resulted in numerous simulated runoff events containing > 10 µg/L hexazinone at the closest sampling station. Groundwater (baseflow) concentrations approaching or exceeding the California 10 µg/L standard are also expected to persist into the second winter (rainy season).

If, however, the herbicide application is applied between April and June, no runoff or groundwater (baseflow) concentrations > 10 µg/L are

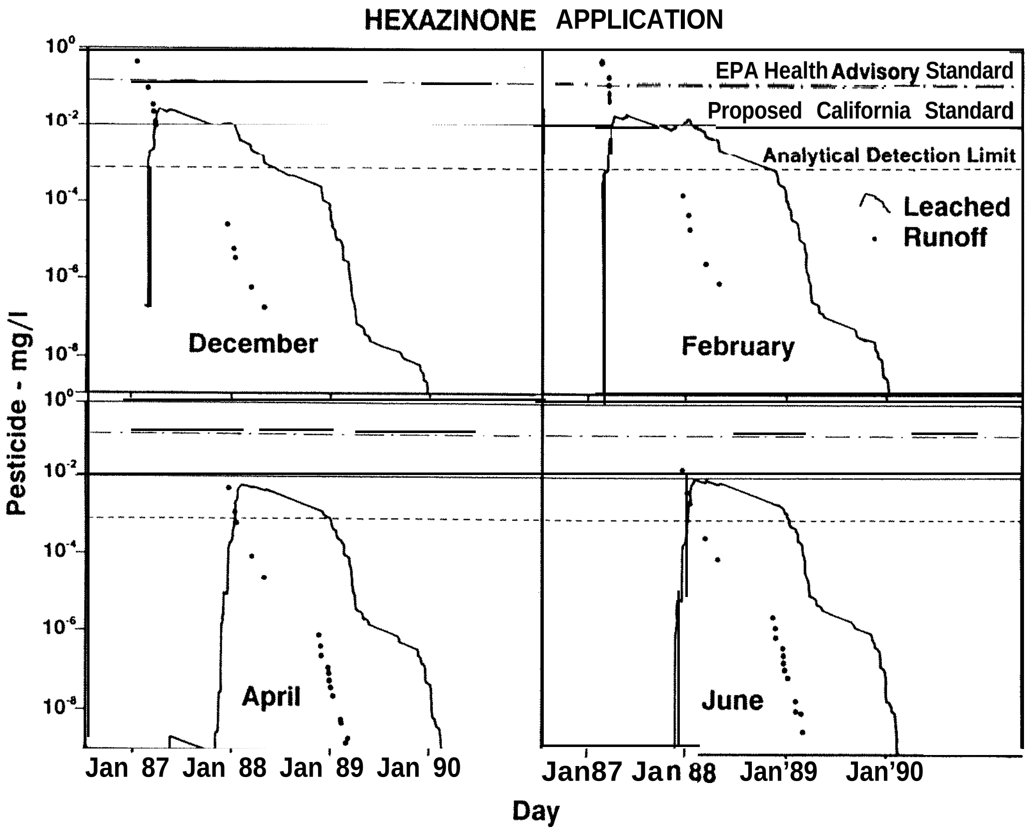

Figure 3. Simulated **(PRZM)** effect of timing of herbicide application on the level of **hexazinone** in runoff and groundwater (baseflow). A **hexazinone** application of 1 kg **ai/ha** was simulated to occur 1 December 1986, 1 February 1987, 1 April 1987, or 1 June 1987, on Josephine soils.

predicted. A review of rainfall records indicates that sufficient rainfall (> 5 cm) is expected after April 1 to activate the granular hexazinone. Application after June 1 may be compromised by lack of rainfall.

For monitoring purposes, the PRZM simulations indicate that streamflow concentrations of hexazinone are not likely to persist above the analytical detection level very long (< 3 months). Soil water (leached) could contain detectable levels for up to 2 years. After December and February applications, monitoring will have to be in place as most of the significant residue movement is predicted to occur with mid-winter storm rainfall. However, for both the April and June herbicide applications, there is insufficient water moving through the soil profile to transport herbicide residues until early winter. Again, it is the early-to-mid winter storms in this part of California that produce the rainfall capable of transporting hexazinone through the root zone and across the surface.

Summary And Conclusions

Comparisons of predicted hexazinone concentrations in stormflow from forested watersheds with field data demonstrate that CREAMS, an agricultural runoff model, can be used to predict the herbicide concentrations in stormflow occurring shortly after application. From the standpoint of environmental impact, maximum stormflow residue concentrations usually occur shortly after application unless rainfall is not sufficient and soils are already dry. CREAMS estimated those concentrations within ± 15 percent, but did not account for subsurface movement. Thus, it tends to underpre- diet concentrations that may be influenced by subsurface flow processes.

CREAMS is useful in evaluating alternative forest herbicides for their potential to appear in stormflow. The model predicted the following order of potential for appearance in stormflow in Piedmont watersheds: bromacil > triclopyr > hexazinone > picloram > dicamba. Highly soluble herbicides (picloram and dicamba) with low partitioning ratios (Kd) were not readily lost to stormflow. These compounds move down through the soil profile with infiltrating rainfall and are not available at the soil surface. GLEAMS will likely be more reliable in predicting the movement of picloram and dicamba.

The California simulation indicated the usefulness in guiding applications to reduce offsite movement as well as determine the best times to monitor. Since resources to monitor herbicide applications are extremely limited, models like PRZM are very useful to guide development of monitoring plans.

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VOLUNTARY BEST MANAGEMENT PRACTICES IN SOUTH CAROLINA[1]

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Abstract. The use of Best Management Practices in the forestry community to prevent widespread site degradation of wetlands has been questioned by several sources. State, federal agencies, and conservation groups initiated a survey to assess the degree of voluntary forest practices implementation. A multidisciplinary team developed a standardized form to evaluate sites, and visited 100 sites. Sites were screened to obtain a representation of operation sizes, landowner sizes, forest types, and equipment applications. Distribution across the state was obtained by selecting 50 sites in the Coastal Plain, 40 in the Piedmont, and 10 in the mountains from seven Forestry Commission districts in the state. About 85 percent of sites visited met minimum BMP implementation. Most consistent problems were excessive rutting, and lack of streamside management zones.

Introduction

The Clean Water Act and the agricultural and forestry exemption to Section 404 has required the forest community to ensure that silvicultural practices are in fact not causing environmental problems. The South Carolina Forestry Association published Voluntary Forest Practices (VFP) in 1978 and revised them in 1988. The South Carolina Forestry Commission published Best Management Practices (BMPs) for wetlands in 1988 and followed up with an intensive extension program to inform forestry interests about the program.

In 1990, the South Carolina Forestry Association initiated a monitoring program to determine the degree of voluntary compliance with the BMPs and determine areas where problems exist that should be addressed by future education efforts. The program was organized by the South Carolina Forestry Commission and executed by an eight-person, multidisciplinary team. Results of that monitoring effort are described here.

Sample Methods And Analysis

In each of the state's seven Forestry Commission Districts, a

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sample of 10 to 20 sites were selected at random from aerial photographs. From these samples, sites were chosen to represent a range in ownership, size of harvest, and type of logging operation. In each case, permission to study the site of the landowner was obtained and landowners were questioned about their knowledge of BMPs and their use of a consulting or experienced forester. The evaluation team then visited the site to evaluate the degree of compliance without knowing the owner or the logging contractor involved. Observers were selected to represent a range of interests, including research, industry, wildlife management, regulation, and nature conservation. Standard questions were provided for observers to answer in order to make measurements less subjective; whenever possible, questions were designed to be answered with a yes or no. Observations from each site were then compiled to represent a consensus of the group.

First, observers addressed site location, the nature of the ownership (large or small private, public , or industrial), and the size of the area harvested.

Second, they documented site characteristics (type and amount of wetland, soil series, drainage, and type of timber).

Third, they evaluated construction of roads. Roads are a major concern because of their high potential site damage and because some landowners might consider using the silviculture exemption to conceal development. Roads were classed as main access or limited use based on their construction and placement on the site. Specific points addressed in the state BMPs are height and width of the road, nature of stream crossings, and presence of erosion.

The fourth area of interest was the effect of the harvesting system and skid trails on the site. Points of concern were stream crossings that might cause erosion or change the hydrology of the site, and the extent and severity of rutting. The nature, location, and distribution of log decks were monitored along with the amount of debris left. Garbage left from the logging operation and oil spills were also noted. Regeneration and apparent site preparations methods were noted.

The fifth and in many ways the most important area of concern was the handling of stream management zones (SMZs) . The state BMPs expressly address SMZs primarily for navigable streams, but it was apparent in doing the survey that many small flowing and intermittent streams are also sensitive to logging damage. Observations made in SMZs included slope to the stream, width of the primary SMZ, if present, the residual overstory basal area, indication of machinery used in the SMZ, logging debris in the stream and bank erosion. If the slope to a stream exceeds 5 percent, BMPs call for a secondary SMZ. Impact on secondary SMZs was evaluated.

Sixth, observers listed sensitive resources, major problems with the silvicultural operation, and practices that were done well.

Finally, individual observers summarized their observations by rating specific items as acceptable, unacceptable, or not applicable. Rated items were main and limited use roads, skid trails, rutting, log decks, SMZs (navigable and non-navigable), and on- and off-site impacts. Observers also assigned compliance ratings of: (1) 90 percent or better; (2) 60 to 89 percent; or (3) less than 60 percent. The results of the survey were then summarized by site, geographic region, and as averages for the whole state.

Results

The landowner responses indicated that only slightly over half of them (56 percent) were aware of Voluntary Forest Practices (VFPs) and wetland BMP guides (Table 1). Eighty-three percent had a written logging contract, but only 37 percent of the landowners had required compliance with some standards in their contracts. However, 96 percent of the landowners were happy with the way in which the silviculture operation was conducted. From the landowner responses, 72 percent had professional foresters on their staffs or have sought professional assistance in their operation.

Table 1. Landowner response to question concerning logging sales.

Quest ion asked	Yes	No
	----- (percent) -----	
Aware of VFP guidelines	56	44
Aware of BMP guidelines	56	44
Had a written contract	83	17
Required compliance	37	63
Landowner satisfaction	96	4
Professional advice	72	28

With the landowners' response in hand, the survey group visited each site and critically evaluated the BMPs listed above. The group's analysis indicated that between 84 and 91 percent of the roads met the specifications outlined in the BMPs (Table 2). Problems were slightly less evident in the Piedmont and Mountains than in the Coastal Plain. Lack of adequate drainage and culverts, improper stream crossings, and erosion were some of the problems observed.

Skid trails were the source of slightly more problems than roads. The observations indicate that between 73 and 92 percent of the sites with trails met the guides outlined in the BMPs. As with roads, skid trail problems were more common in the Coastal Plain. This area appears to be more of a problem than the Piedmont or Mountains. Most of the problems with skid trails were with stream or drainage crossings.

Rutting appears to be a problem associated with the Coastal Plain, and brings up the question, "What is an unacceptable level of rutting?" In our survey, the group consensus was that the rutting is excessive when the hydrology of the sites is altered either through drainage or flooding of the site. These impacts can be minimized through careful selection and design

Table 2. Proportion of sites observed that complied with portions of the BMP Guides and meeting overall standards by region.

Region[1]	Roads	Log decks	Skid trails	Rutting	SMZs	Off- and on-site impacts	Overall compliance
CP	84	83	73	67	64	57	83
MCPAP	90	96	88	83	43	74	89
P	91	95	82	90	38	78	85
M	91	100	92	100	44	89	92

[1] CP = Coastal Plain; MCPAP = Mixed Coastal Plain and Piedmont; P = Piedmont, and; M = Mountains.

of equipment, location of skid trails on higher ground, and limiting operations to drier seasons.

Log decks were not a major problem. Compliance was rated between 83 to 100 percent . Most decks were well located on high ground and away from streams or drainages to minimize site impact. A problem that appeared frequently was garbage on sites, including oil or hydraulic fluid spills. The need for education about Streamside Management Zones (SMZs) or riparian zones is apparent, since only slightly over half the sites met the BMP requirements. A closely related communications problem is the low proportion of landowners who were aware of the BMPs (roughly 56 percent). Poor management of SMZs occurred in all regions of the state. Problems were clear-cutting to the stream, operating equipment in the SMZ, and leaving logging debris in the stream. Overall on-site impacts of the silvicultural operations represented 57 to 89 percent compliance across the state. The worst problems were in the Coastal Plain where the largest portion of the sites were jurisdictional wetlands.

BMP compliance effects where the operation could affect environmental values of streams or wetlands off-site was similar on site compliance. Again this reflected the proportion of the area in wetlands. In addition to on-site compliance, evaluation was made on the impact that the silviculture operation was having on- and off-site wetland functions. This involved primary sediment in streams or potential stream sedimentation. These values were similar to the on-site impacts. Overall compliance for the state was 85.7 percent which was higher than we had anticipated. This rating is not a reason for complacency, it also shows that 14 percent of sites did not meet the minimum BMP guidelines. Some logging sites had severe problems that could affect public attitudes and reflect unfavorably on the whole industry. The survey identified SMZs as the place where the greatest emphasis is needed in extension work. To demonstrate its environmental concern, the Forestry Commission should strive to improve SMZ management.

It was apparent from the survey, that to obtain reasonable public acceptance of and compliance with the voluntary BMPs, a continuing education program will be needed to keep the issue in front of the individuals practicing forestry in ecologically sensitive areas.

EFFECTIVENESS OF THE TENNESSEE DIVISION OF FORESTRY'S BEST MANAGEMENT PRACTICES TO CONTROL DEGRADATION OF AQUATIC RESOURCES DUE TO CLEARCUTTING IN THE PICKETT STATE FOREST [1]

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Abstract. The Tennessee Division of Forestry (TDF) was mandated to develop and implement best management practices (BMPs) for the protection of surface waters adjacent to timber harvest areas. A paucity of information exists on the effectiveness of BMPs to control the degradation of watersheds by silviculture activities in Tennessee. This study determined if conservation measures prescribed by the TDF would protect the Rock Creek watershed from impacts caused by clearcutting. Streams in the study area historically maintained excellent water quality of low nutrient and metals concentrations and alkalinity below detectable levels. Water chemistry (nutrients, solids, total organic and inorganic carbon, metals, and herbicides), benthic macroinvertebrates (diversity, density, and taxa richness), and fish production were studied at sites above, adjacent to, and below logged areas. Logging did not noticeably affect water quality or aquatic fauna in the Pickett State Forest.

Introduction

Logging and associated activities are potential sources of water pollution (Tennessee Department of Conservation 1985). Major sources include haul roads, skid trails, log landings, riparian canopy removal, and treetops in streams. Impacts on aquatic systems from logging can be grouped into five main categories: stream flow, water temperature, turbidity and sedimentation, dissolved nutrients, and allochthonous organic detritus (Lynch et al., 1977). Impacts on any of these factors may affect aquatic biota.

To minimize environmental impact and maintain water quality, the Tennessee Department of Conservation (1985) established a set of best management practices (BMPs) for logging on state forest land. The major BMPs implemented in the Pickett State Forest study area were:

1. Streamside management zones (SMZs) established between logged areas and streams ($\geq$ 14 m);

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2. Haul road and skid trails built away from streams and along contours whenever possible;
3. Timber harvesting conducted during the driest season (May to September);
4. The size of logging stands minimized;
5 Logging stands distributed throughout the watershed to avoid concentration of impacts to a small area;
6. Silvicultural operations restricted to a minimal time period, and;
7. Highly disturbed areas (log landings, haul road, and skid trails) restored by techniques such as grass seeding and installation of broad-based dips.

Although such BMPs have been used successfully in previous studies (Aubertin and Patric 1974; Corbett et al., 1978; Patric 1980; Martin et al., 1984; Lynch et al., 1985), their effectiveness in Tennessee had not been demonstrated.

This study was designed to determine the extent of logging impacts using BMPs on stream water quality and fauna. Objectives to accomplish this goal were to:

1. Characterize baseline water chemistry, creek chub (*Semotilus atromaculatus*) populations, and benthic macroinvertebrate communities;
2. Determine effects of logging on water chemistry, and;
3. Determine effects of logging on communities of the aquatic fauna.

Study Area

Pickett State Forest lies on the Cumberland Plateau in Pickett County, Tennessee. Soils in the study area are of low natural fertility and low pH. Parent materials of sandstone and sandy shale are the base for a highly permeable, sandy soil. Slopes in the study area varied, from 3 to about 60 percent. Common trees and shrubs of the area included Virginia pine (*Pinus virginiana*), scarlet oak (*Quercus coccinea*), white oak (*Q. alba*), black oak (*Q. velutina*), red maple (*Acer rubrum*), various hickories (*Carya* spp.), shortleaf pine (*P. echinata*), eastern hemlock (*Tsuga canadensis*), and mountain laurel (*Kalmia latifolia*) (Soil Conservation Service, in press).

Timber was harvested in three stands which were spaced about 0.75 km apart. Stand I (10.5 ha) was located at the confluence of Rock Creek and Little Rock Creek (Fig. 1). Stand II (12.1 ha) was positioned about 1 km from all streams. Stand III (17.4 ha) was within 0.3 km from Rock Creek. Because of the proximity of Stand I to streams, silvicultural activities in Stand I would have the greatest potential impacts on adjacent streams; therefore, sampling design was centered around Stand I.

Methods

Procedures used in this study included implementation of silvicultural practices (including BMPs), water quality analysis, and analysis of aquatic

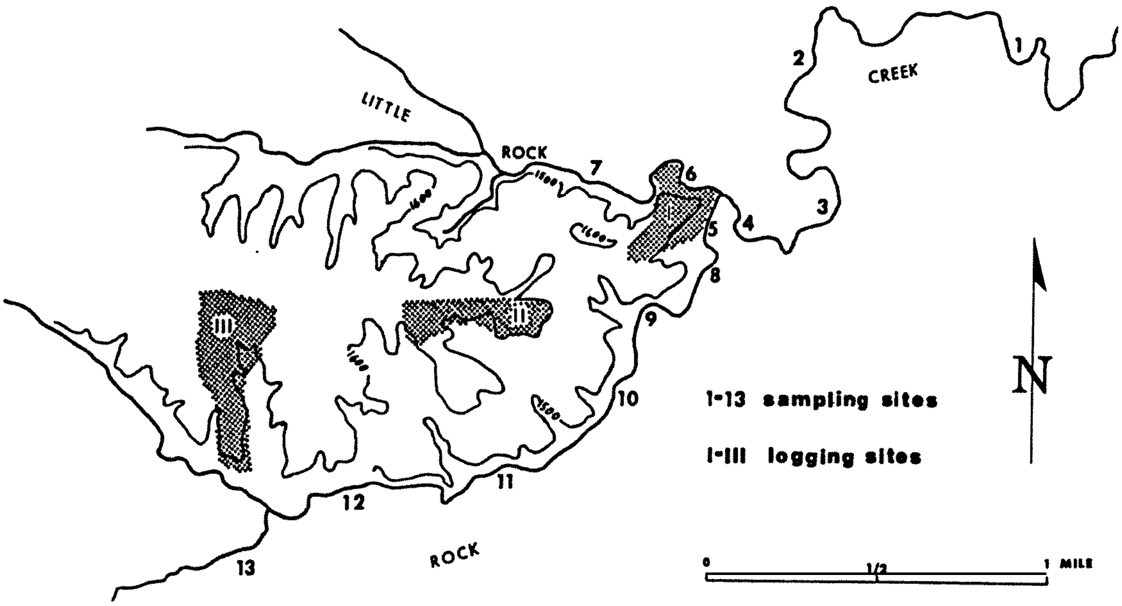

Figure 1. Location of water quality monitoring stations on Rock Creek and Little Rock Creek, Pickett State Forest.

faunal communities (benthic macroinvertebrates and creek chub) within the Rock Creek drainage. BMPs were previously discussed. All methods are described by Curtis et al. (1990) and by Pelren (1990). Further details of silvicultural methods are detailed by Tennessee Department of Conservation (1985).

Because of the marginal quality of timber, a selective harvest was made from May to September 1988. Some trees were left standing for wildlife dens and seed; natural regeneration was the plan for each stand. All other trees were slashed (75 to 255 mm dbh) or killed by herbicide application. Hardwoods under 75 mm dbh (diameter at breast height) were sprayed with a Garlon™/Sidekick/diesel fuel mixture. Hardwoods over 255 mm dbh were injected with Tordon™. Slash remained where it was felled, and burning was deemed unnecessary.

Eleven sampling stations were established on Rock Creek, and two sampling stations were chosen on Little Rock Creek (Fig. 1). The locations of the sampling stations were selected to monitor aquatic chemical, physical, and biological conditions upstream and downstream of the proposed timber harvest areas and to provide a minimal baseline water quality data of the streams adjacent to the entire timber harvest area. Monitoring Stations 8, 5, 7, and 6 were located to provide upstream and downstream data delineating the impact of timber harvest activities. The major monitoring effort focused on these sampling sites. In addition, sampling Sites 4 and 2, which were downstream from. the confluence of Rock Creek and Little Rock Creek, were more intensely monitored. These six sampling sites (e.g., 2, 4, 5, 6, 7, and 8) were generally sampled once a month for 29 months. During and after timber harvest, this sampling frequency was increased to twice a month for 5 months.

Field measurements (e.g., temperature and dissolved oxygen) were taken at thirteen sites. Water samples were collected and stream flow gauged with a Marsh-McBirney™ flow meter at six sites (II, **4, 5, 6, 7,** and **8).** Water samples were collected in 4-L, collapsible, polyethylene containers; labeled; and placed in a backpack with Blue Ice™ for transport to the laboratory at Tennessee Technological University. In addition to the 4-L sample, one glass vial was also filled with water at each site for total organic carbon (TOC) and total inorganic carbon (TIC) measurements. Table 1 lists the water quality parameters and associated analytical methods that were measured on the water quality (W/Q) samples.

Seven water samples were analyzed for the following herbicides: 2,4-D, picloram, and triclopyr. Picloram and 2,4-D are the active ingredients (a.i.) of Tordon, and triclopyr is an active ingredient in Garlon. Herbicide samples were aqueous grab samples collected in liter, amber glass bottles with Teflon-lined caps. Analysis was performed according to Standard Methods 509B (American Public Health Association 1985). The detection limit for each herbicide monitored was 0.02 μg/L.

Biotic surveys were conducted quarterly throughout the study at sampling Sites 2, 4, 5, 6, 7, and 8. Benthic macroinvertebrate quantitative samples were collected with a 0.1 m^2 Surber™ sampler and preserved with about 50 ml of 5- to lo-percent solution of formalin for later laboratory identification. Diversity indices, densities, and taxa richness were calculated.

A section of stream at each site was sampled by backpack electroshocker for fish; populations were estimated by the depletion method. Lengths and weights were used in conjunction with population estimates for an estimate of production.

Results And Discussion

Water Quality

The water characteristics of Rock Creek and Little Rock Creek prior to harvest are presented in Table 2. The data indicate a high quality water source with little mineral, nutrient, and organic matter present. The major source of organic matter introduced to the streams was most likely derived from leaf litter during the fall. Due to the pristine water quality, Rock Creek and Little Rock Creek were considered to be very sensitive indicators of possible increased nutrient, mineral, and organic mass loadings resulting from the timber harvest activities. The pH of the water before timber harvest ranged from 4.8 to 6.2 which reflected the acidic nature of the soils and the geology through which the water within the watershed flowed.

Table 1. **Water quality** parameters measured.

Parameter	Units	Method[1]/reference[2]	Technique
pH, lab	--	S.M. 423	Electrometric, meter
Alkalinity	($mgCaCO_3/L$)	S.M. 403	Titrimetric, pH 4.5
Total dissolved solids (TDS)	(mg/L)	S.M. 2098	Gravimetric, dried at 180°C
Total suspended solids (TSS)	(mg/L)	S.M. 209C	Gravimetric, dried at 103%
Sulfate	($mg\text{-}SO_4/L$)	S.M. 429	Ion chromatography/conductivity
Chloride	(mg/L)	S.M. 429	Ion chromatography/conductivity
Total organic carbon (TOC)	(mg/L)	S.M. 505B	Persulfate-UV oxidation/ IR detection
Total inorganic carbon (TIC)	(mg/L)	S.M. 505B	Acidification/IR detection
Total phosphorus	(µg-P/L)	S.M. 424F	Digestion/ascorbic acid colorimetric
Total nitrogen	(mg-N/L)	Pitts & Adams	Modified persulfate oxidation
Organic nitrogen	(mg-N/L)	Pitts & Adams	Calculation
Ammonia	(mg-N/L)	S.M. 417G	Automated phenate/colorimetric
Nitrite	(mg-N/L)	S.M. 418F	Automated diazotization colorimetric
Nitrate	(mg-N/L)	S.M. 418F	Automatedcadmium reduction/Colorimetric
Iron, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Manganese, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Calcium, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Magnesium, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Sodium, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Potassium, total	(mg/L)	S.M. 305	Nitric acid digestion, inductively coupled plasma (ICP) spectroscopy
Herbicides (2,4-D, picloram, Triclopyr)	(µg/L)	S.M. 509B	Ether extraction, hydrolysis, methylation, concentration, GC/ECD supelcoport 100/120)

[1] American Public Health Association/American Water Works Association/Water Pollution Control Federation 1985.

[2] Pitts and Adams 1987.

Table 2. Water quality conditions of Rock and Little Rock Creek before, during, and post timber harvest.

Parameter		Rock Creek Preherves t	Rock Creek During and pest harvest	Little Rock Creek[1] Preharvest	Little Rock Creek[1] During end post harvest
Flow[2] (ft^3/sec)	Mean	3.2	2.3	1.4	1.0
	N	28	34	27	34
	SD	3.2	1.9	1.5	1.0
	Range	0.4-12.7	0.5-6.3	<0.1-6.0	<O.l-3.7
Temperature (°C)	Mean	11	12	12	13
	N	29	37	28	38
	SD	4.7	5.7		5.4
	Range	4-17	1-20	5 %	2-20
Dissolved oxygen hydrolab (mg/L)	Mean	10.8	10.5	10.4	10.3
	N	29	36	28	36
	SD	1.8	1.6	1.7	
	Range	9.0-13.9	8.2-14.4	8.5-13.8	8.0-1:::
pH	Mean	5.6	5.7	5.3	5.5
	N	30	38	30	34
	SD	0.04	0.06	0.05	0.04
	Range	5.0-6.2	4.6-6.3	4.8-5.9	5.1-6.2
Total dissolved solid (mg/L)	Mean	26.7	21.0	23.9	21.1
	N	26	38	26	38
	SD	10.4	10.7	11.3	10.0
	Range	16.8-51.0	3.2-53.0	8.6-51.0	2.4-43.2
Total suspended solids[2] (mg/L)	Mean	3.7	2.3	4.1	4.9
	N	24	36	24	36
	SD	4.2	2.3	5.3	8.2
	Range	<0.1-18.4	0.2-14.0	0.2-24.1	0.3-36.7
Sulfate (mg/L)	Mean	4.4	3.8	4.6	4.1
	N	30	38	30	38
	SD	2.3	1.5	2.3	
	Range	1.4-8.3	1.7-6.2	1.6-8.4	2.3-k;
Chloride (mg/L)	Mean	0.67	0.60	0.69	0.67
	N	23	38	24	38
	SD		0.1		
	Range	0.4-z	0.4-1.0	0.5-E	0.4-E
Total organic carbon (mg/L)	Mean	3.8	2.6	4.4	2.7
	N	28	36	28	36
	SD	2.44	2.47	3.08	2.59
	Rang(	0.9->10.0	0.5-10.2	0.8->10.0	0.8-10.2
Total inorganic carbon (mg/L)	Mean	0.77	0.64	0.73	0.62
	N	26	38	26	38
	SD	0.36	0.34	0.30	0.36
	Range	0.23-1.73	0.13-1.53	0.32-1.52	0.14-1.74
Total phosphorus[2] (µg P/L)	Mean	9.3	9.7	10.6	13.6
	N	30	38	30	38
	SD	5.3	7.3	6.8	14.2
	Range	<10-22	<10-33	<10-30	<10-50
Total nitrogen (mg N/L)	Mean	0.16	0.17	0.18	0.18
	N	30	38	30	38
	SD	0.15	0.10	0.16	0.09
	Range	<0.05-0.74	<0.05-0.50	<0.05-0.72	0.08-0.44
Organic nitrogen[2] (mg N/L)	Mean	0.11	0.11	0.12	0.13
	N	30	38	30	38
	SD	0.14	0.06	0.16	0.08
	Range	<0.05-0.66	<0.05-0.26	<0.05-0.66	<0.05-0.44

Table 2. Continued.

Parameter		Rock Creek Preharvest	Rock Creek During and post harvest	Little Rock Creek[1] Preharvest	Little Rock Creek[1] During and post harvest
Ammonia[2] ($mg\ NH_3$-N/L)	Mean	0.04	0.06	0.05	0.06
	N	30	38	30	38
	SD	0.03	0.08	0.04	0.06
	Range	<0.02-0.15	<0.02-0.46	<0.02-0.20	<0.02-0.30
Nitrite* ($mg\ NO_2$/L)	Mean	<0.01	<0.01	<0.01	<0.01
	N	30	38		38
	SD	--	--	0.0%	0.002
	Range	<0.01	<0.01	<0.0l-0.06	<0.01-0.02
Nitrate[2] ($mg\ NO_3$/L)	Mean	0.02	0.02	0.02	0.02
	N	30	38	30	38
	SD	0.02	0.01	0.02	0.08
	Range	<0.0l-0.08	<0.0l-0.07	<0.0l-0.09	<0.01-0.05
Total iron[2] (mg/L)	Mean	0.26	0.23	0.32	0.23
	N	30	38	30	38
	SD	0.21	0.19	0.26	0.21
	Range	0.04-0.68	0.01-0.62	0.03-0.81	<0.0l-0.68
Total manganese[2] (mg/L)	Mean	0.03	0.03	0.04	0.04
	N	28	38	28	38
	SD	0.02	0.01	0.02	0.01
	Rang	<0.01-0.39	<0.01-0.05	<0.01-0.11	<0.01-0.07
Total calcium (mg/L)	Mean	0.72	0.70	0.55	0.55
	N	28	38	28	38
	SD	0.25	0.13	0.17	0.10
	Range	0.39-1.31	0.51-1.00	0.33-0.89	0.37-0-77
Total magnesium (mg/L)	Mean	0.44	0.41	0.46	0.47
	N	28	38	28	38
	SD	0.15	0.13	0.13	0.13
	Range	0.26-0.79	0.06-0.52	0.25-0.63	0.12-0.68
Total sodium[2] (mg/L)	Mean	0.3	0.4	0.3	0.3
	N	28	38	28	38
	SD	0.1	0.1	0.1	0.1
	Range	<0.l-0.5	<0.1-0.5	<0.1-0.7	<0.l-0.5
Total potassium (mg/L)	Mean	0.6	0.6	0.7	0.6
	N	24	38	24	38
	SD				0.3
	Range	0.2-E	0.2-E	0.4-z	0.4-1.5

[1] Rock Creek values are calculated from Sites 8 and 5; Little Rock Creek values are from Sites 7 and 6 only.

[2] Calculated sample means include value of half of detection limit.

Once the timber harvest commenced, the pH of Rock Creek and Little Rock Creek remained within the range measured prior to harvest; i.e., 4.6 to 6.3 and 5.1 to 6.2, respectively. No significant pH shift occurred before or after harvest activities. During low flow periods when springs supplied the water to the creeks, pH increased and certain minerals such as iron also increased in the water.

Iron, manganese, calcium, magnesium, sodium, and potassium were measured at all six sites for the 2½-year monitoring period. Table 2 lists average mineral values prior to, during, and after timber harvest activities commenced. The data support the short hydraulic retention time in the watersheds and the lack of dissolution of minerals from soils and geological formations by percolate water that eventually reaches the streams. The greatest concentrations of iron, manganese, calcium, magnesium, and potassium were recorded prior to the beginning of timber harvesting (May 17, 1988). These high values were most likely due to low rainfall and low flow conditions. Increased flow in the streams appeared to dilute the iron and sodium concentrations.

Seasonal temperature trends occurred within both streams with temperatures ranging from near 0 to 23°C. Unlike some logging operations, overhead riparian canopy at our study area was not removed. Thus, stream temperature was unaffected by logging.

Stream dissolved oxygen (DO) fluctuations apparently were caused by changes in water temperature and barometric pressure. DO remained at or near saturation at all sites throughout the study, and ranged from about 8.0 to 14.4 mg/L (Fig. 2). This data indicates that biochemical oxygen demand was probably low, reflecting low organic and nutrient loads.

Rock Creek and Little Rock Creek were fed by surface runoff and shallow springs with little dissolution of minerals present in the soils, sandstone, and shales. Total dissolved solids (TDS) ranged from 2.4 to 53.0 mg/L (Fig. 3). Although the maximum value was measured downstream of Stand 1 during logging, a similar concentration (57 mg/L) occurred prior to logging. A higher concentration in TDS appeared because of longer water contact with salts. During periods of minimal rainfall when baseflow conditions existed, TDS concentrations were highest ranging from 15 to 53 mg/L. TDS levels in the streams decrease after rainfall events. With the low levels of TDS present in the streams, associated anions and cations were at low levels. Timber harvest activities did not appear to have an impact on the ions in Rock Creek and Little Rock Creek.

Suspended solids may adversely affect fish and food population [European Inland Fisheries Advisory Commission (EIFAC) 1965] by: (1) direct action on aquatic life; (2) preventing successful development of fish eggs or larvae; (3) modifying natural movements and migrations of fish, and; (4) reducing or altering food chain interaction. Settleable materials which blanket the bottom of water bodies can damage invertebrate populations, block gravel spawning beds, and alter oxygen regions (EIFAC 1965, Edberg and Hofsten 1973). Major increases in TSS during heavy logging are well documented (Tebo 1955; Cordone and Kelley 1961; Haupt and Kidd 1965; McClurkin et al. , 1985; Platts et al., 1989). Suspended solids of 390 mg/L have been reported to have detrimental effects upon bottom aquatic invertebrates in small watershed streams (Tebo 1955). At monitoring Sites 8 and 5, the total suspended solids (TSS) values in Rock Creek prior to timber harvest ranged from below the detection limit of 0.1 mg/L to a high value of 18.4 mg/L (Fig. 4). Once harvest activities began in May 1988, TSS concentrations ranged from $\leq$ 0.1 mg/L to a maximum of 14.0 mg/L at Site 5. While the TSS concentration at site 5 was at a maximum, the TSS concentration at the upstream monitoring site was 5.8 mg/L. This increase in suspended solids from Sites 8 to 5 in June 1988 appeared to be seasonal since water at Site 5 (18.4 mg/L) contained a greater concentration of TSS than water at Site 8 (9.1 mg/L) during June of the previous year, 1987 (Fig. 4).

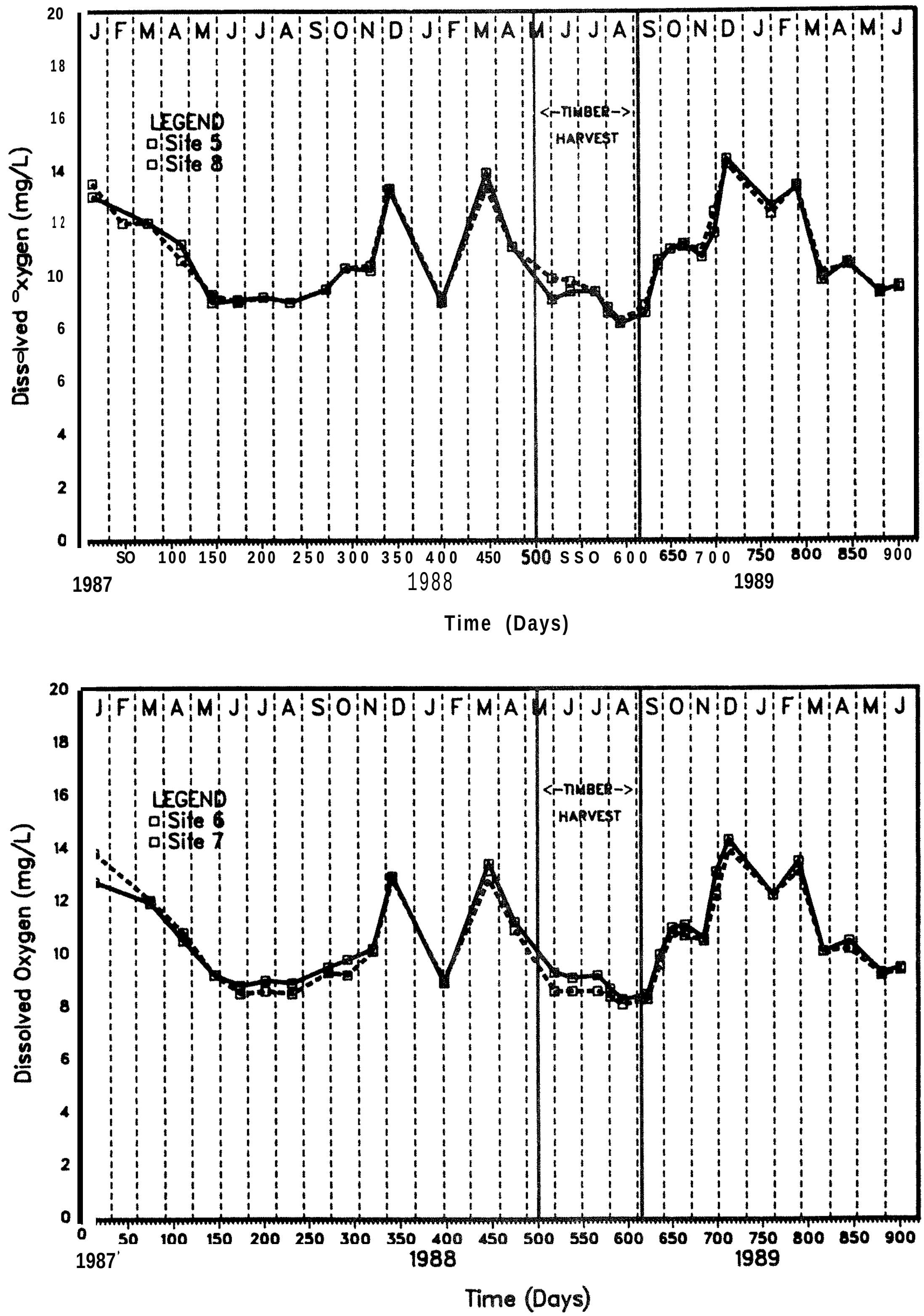

Figure 2. Dissolved oxygen values for Rock Creek and Little Rock Creek, Sites 5, 6, 7, and 8.

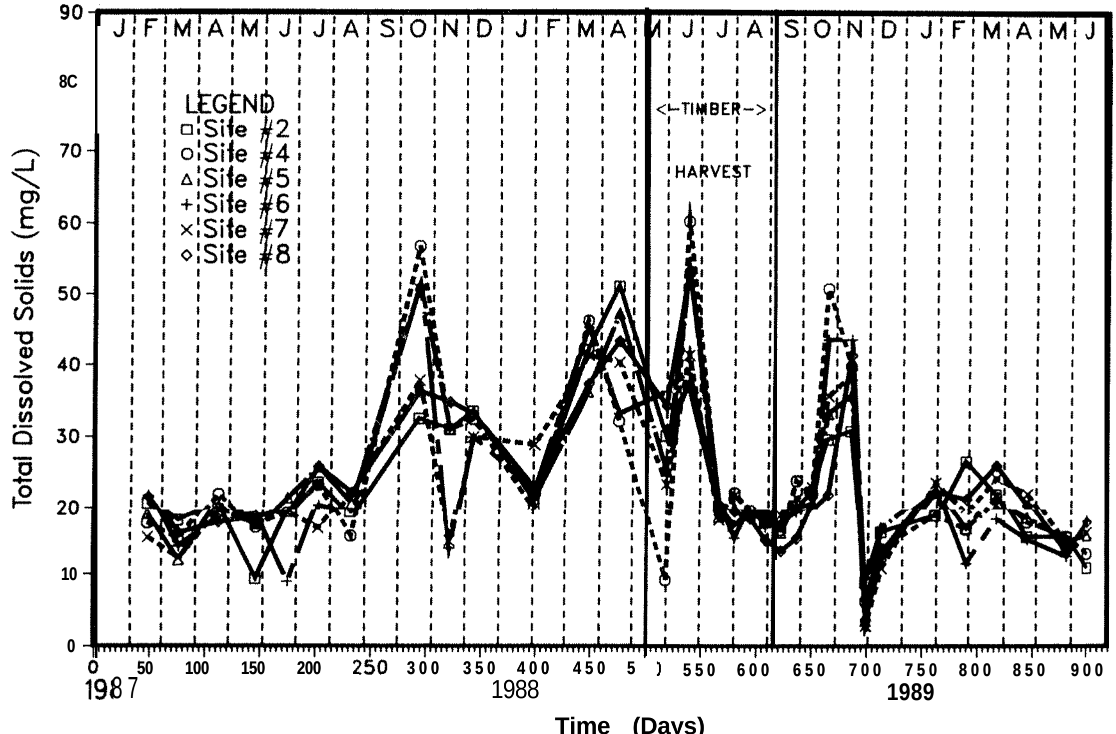

Figure 3. Total dissolved solids concentrations in Rock Creek and Little Rock Creek

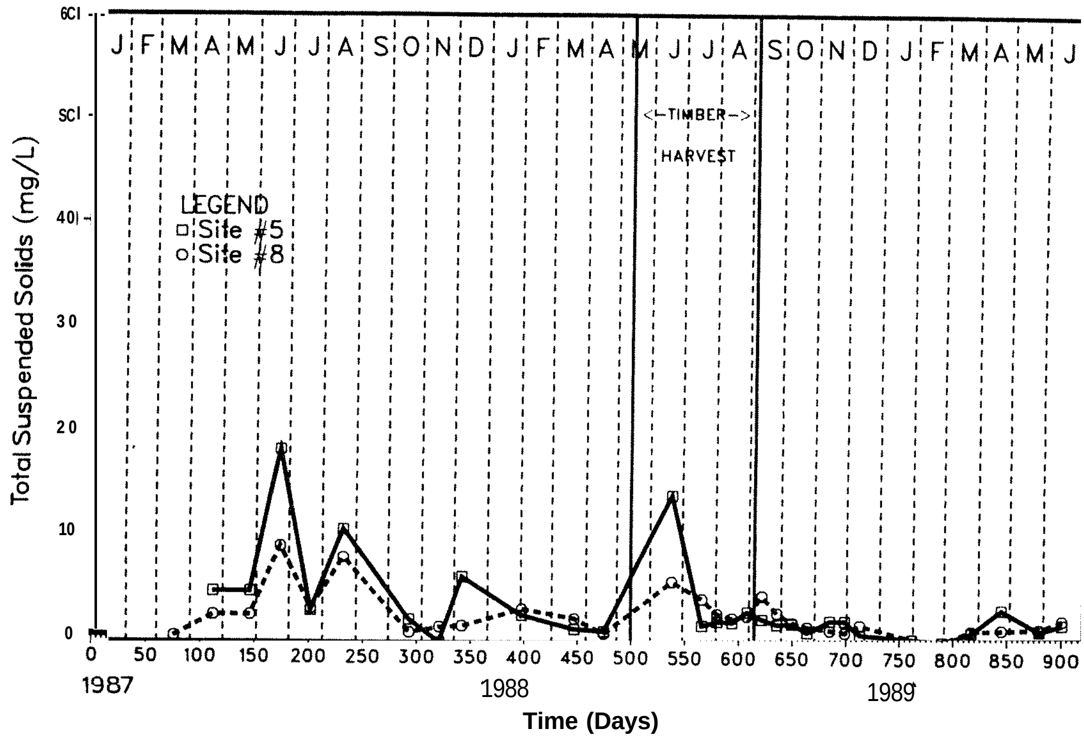

Figure 4. Total suspended solids concentrations in Rock Creek at Stations V and VIII.

Average TSS levels at Sites 8 and 5 were 3.0 and 5.0 mg/L, respectively, prior to harvest, and 2.1 and 2.3 mg/L after harvest activities ended. There appeared to be some variation of TSS with rain input, but no consistent correlation was observed.

The high TSS values recorded in Little Rock Creek at Sites 6 (36.7 mg/L) and 7 (31.0 mg/L) on June 21, 1988, occurred during the timber harvest and a month of low rainfall (17 mm). Site 7 was thought to be above the harvesting activity. The TSS data indicated that an increase in TSS within Little Rock Creek normally occurred during the summer months. TSS levels in Little Rock Creek averaged 4.1 mg/L at Site 7 and 3.8 mg/L at Site 6 prior to timber harvest. After timber harvesting activities commenced, the average TSS concentrations in Little Rock Creek were 5.1 mg/L at Site 7 and 4.6 mg/L at Site 6.

The concentration of TSS downstream from the confluence of Rock Creek and Little Rock Creek remained relatively constant throughout the monitoring period. The average TSS concentrations at Site 4 were 2.8 mg/L before harvesting activities and 1.7 mg/L after harvesting began. Similarly, at Site 2 the average TSS was 3.1 mg/L before harvest and 1.2 mg/L after harvest commenced.

Nitrogen species and total inorganic carbon (TIC) in the streams remained at baseline throughout the study. Total nitrogen ranged from below the detection limit (0.01 mg/L) to 0.74 mg/L, averaging about 0.17 mg/L for all sites. Concentrations of ammonia, nitrite, nitrate, and organic nitrogen were usually below detection limits. TIC concentrations ranged from 0.11 to 1.73 mg/L, and averaged 0.64 mg/L.

Commercial herbicides were used after harvest to reduce competitive regrowth of undesirable species. Seven water samples were tested for three active ingredients. Results of herbicide analyses are shown in Table 3.

Table 3. Herbicide concentrations in Rock Creek and Little Rock Creek during study period (February 1987 to June 1989).

Date collected	Site	Concentration 2,4-D	Triclopyr	Picloram
		----------	(µg/L)	----------
06/21/88	4	<0.02	<0.02	<0.02
06/21/88	7	<0.02	<0.02	<0.02
02/01/89	4	<0.02	0.10	0.05
02/01/89	7	<0.02	0.06	0.03
06/20/89	4	<0.02	<0.02	0.13
06/20/89	7	0.08	<0.02	0.06
06/20/89	8	0.08	<0.02	0.06

Concentrations of herbicides found were low. Levels of concern are order of magnitudes higher for triclopyr and picloram and are presented in Table 4. Based on available aquatic toxicity data, the low herbicide levels detected in the streams apparently were not a problem. Care in application, however, must be practiced to minimize any transport of herbicides to the aquatic ecosystem.

Benthic Macroinvertebrates

The streams of the Rock Creek drainage maintained diverse benthic macroinvertebrate communities at all sites throughout the study. Shannon diversity values varied from 2.1 to 4.7. Diversity index values of clean streams are usually between 3 and 4 and below 1 in polluted streams (Wilhm 1970).

The range of taxa richness was 27 to 57 taxa in 0.3 m^2. This compares with richness of other small, clean streams also draining into the Big

Table 4. **Bioassay results using common** herbicides and their active ingredients.

Chemical tested	Test organism	Test	Chemical concentration	Reference
Picloram printer font normal 5 0 0 62 (Tordon™)	Bass	48 hr LC_{50}	19.7 mg/L	Brown 1980
2,4-D (Tordon)	Bluegi 11	84 hr LC_{50}	1.0 mg/L	Brown 1980
Triclopyr (Garlon™)	Fathead minnow	Static, acute LC_{50}	245 mg/L	Mayes et al., 1984
Garlon 4™	Daphnia	EC_{50}	1.2 mg/L	Servizi et al., 1987
Garlon 4	Rainbow	$LC5_0$	2.2 mg/L	Servizi et al., 1987
Picloram	*Gammarus lacustris*	LC_{50}	27 mg/L	Hayes and Oliver 1985
Picloram	*Daphnia magna*	LC_{50}	68.3 mg/L	Mayes and Oliver 1985
2,4-D	*Chironomus* sp.	12 hr	21.3 mg/L	Vardia and Rao 1986
Picloram	Lake trout	LC_{50}	4.3 mg/L	Mayes and Oliver 1985
Picloram	Fathead minnows	LC_{50}	55.3 mg/L	Hayes and Oliver 1985
2,4-D	*Daphnia magna*	48 hr, LC_{50}	25 mg/L	Alexander et al., 1985
2,4-D	Fathead minnows	48 hr, LC_{50}	325 mg/L	Alexander et al., 1985
2,4-D	Bluegill	48 hr, LC_{50}	290 mg/L	Alexander et al., 1985
2,4-D	Rainbow trout	48 hr, LC_{50}	358 mg/L	Alexander et al., 1985

South Fork Cumberland River, of which Rock Creek is a tributary (O'Bara et al., 1982; Etnier et al., 1983). Taxa richness exhibited definite seasonal patterns in the Rock Creek drainage (Fig. 5). Fluctuations were probably due to spring insect emergence, appearance of young invertebrates after hatching, predation, and dispersal during high spring stream flow. Heavy logging activities often increase organic matter load which could cause a decrease in taxa richness (Wilhm 1967). The general stability of taxa richness in this study suggests, however, that BMPs were effective in minimizing organic input and otherwise protecting benthic macroinvertebrate communities.

Benthic organism densities ranged between 79 and 10,240 individuals per m^2 in Pickett State Forest. Taxa richness and density data further support the finding that benthic macroinvertebrate communities were not apparently affected by logging activities.

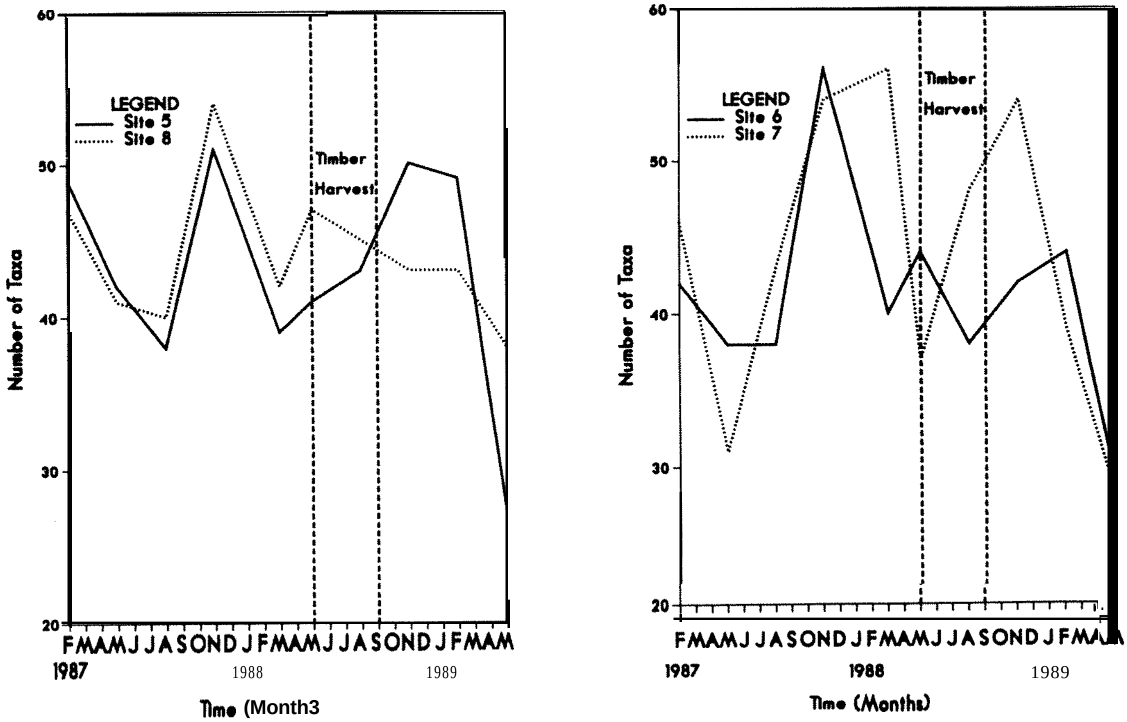

Figure 5. Benthic macroinvertebrates taxa richness at monitoring Stations V, VI, VII, and VIII.

Fish

The study area in Pickett State Forest maintained a fish population of low diversity. Creek chub (<u>Semotilus atromaculatus</u>) was the species that dominated the streams of the Rock Creek drainage. Production of creek chub generally followed an annual cycle with greatest production usually occurring between November and February (autumn to winter, Tables 5 and 6). The

Table 5. Production of 2-year-old Creek Chubs for each period at Sites 2, 4, 5, 6, 7, and 8.

Year and period	Site 2	4	5	6	7	8
	------------- (g/m²/quarter) -------------					
1987 :						
winter to spring	.0655	.0314	.1186	.0854	.1820	.0626
spring to summer	.0123	.1348	.1257	.0719	.0280	.0302
summer to autumn	-.0341	-.0316	-.0238	-- *	.1849	-.0105
autumn to winter	.0070	.2234	.0883	--	.0767	.0787
1988:						
winter to spring	.0168	.0928	.0368	--	*0105	--
spring to summer	-.0021	.0126	-.0325	--	-.0587	--
summer to autumn	.0020	-.0636	.0373	--	--	-.0109
autumn to winter	.0090	.2280	.2566	--	--	.2442
1989:						
winter to spring	.0185	.0435	.0078	--	.0496	.0118

* Population es timate not available because the numbers of fish collected in each pass did not satisfy requirements for a valid depletion population estimate.

apparent production increase during the period may have been a result of fish moving into the study sites to over-winter in the pools (Moshenko and Gee 1973). Production of age two and three fish declined from winter to spring. This decrease in production may have resulted from stress due to low water temperature, predation, and movement out of sampling sites to riffles during spring spawning migrations. If the streambed was affected by siltation resulting from silvicultural activities, creek chub reproductive success might have decreased (Stair et al., 1984). Production trends, however, followed the same patterns throughout the study at all sites, indicating no apparent effects on the creek chub populations due to timber harvest.

Summary And Conclusions

From May to September 1988, TDF had three stands of timber harvested in the Pickett State Forest. Prior to harvest, TDF implemented BMPs to protect the environmental condition of the adjacent streams: Rock Creek and Little Rock Creek. SMZs were established with the minimum distance between the stream and the logged area being 14 m. Haul roads were located on the top of a ridge with no stream crossings. Skid trails followed spurs and were kept at least 14 m from all streams. Logging stands were small (10.5

Table 6. Production of 3-year-old Creek chubs for each period at Sites 2, 4, 5, 6, 7, and 8.

Year and period	Site 2	4	5	6	7	8
	-------------		(g/m²/quarter)		------------	
1987:						
winter to spring	--	* .0094	.0109	.0047	--	--
spring to summer	.0233	-.0022	.0000	.1476	--	.0048
summer to autumn	.0206	-.0031	-.0034	--	.1055 -	.0024
autumn to winter	--	.1484	.0785	--	.2665	.0259
1988:						
winter to spring	.0260	.0751	.0524	.0381	-.1557	--
spring to summer	-.0446	.0145	.0202	.0476	.1804	
summer to autumn	--	-.0132	.0000	.0757	--	-.0049
autumn to winter	--	.1421	.0938	.1686	--	.2270
1989:						
winter to spring	.0061	.0477	.0280	--	.1096	-.0136

* Population estimate not available because the numbers of fish collected in each pass did not satisfy requirements for a valid depletion population estimate.

to 17.4 ha) and situated away from other stands to diffuse impacts to the watershed. Highly disturbed areas were seeded with mixed grasses and mulched in October 1988. Broad-based dips were also installed in a portion of the haul road to impede overland flow. Furthermore, the duration of the logging activities was limited to less than 2 months/stand to minimize environmental impacts.

The water quality of the streams adjacent to the harvested areas was monitored 17 months prior to timber harvest, during timber harvest activities, and 10 months after timber harvesting was completed. During the same period of time, macroinvertebrates and fish populations also were measured. Based on the data collected during the study, BMPs implemented at the timber harvest areas were apparently effective at preventing any detrimental impact on the adjacent streams. The streams remained very pristine with apparently little organic or nutrient inputs. Total nitrogen concentrations in the streams varied from < 0.05 to 0.74 mg/L at the monitoring station immediately upstream from Stand I. Average total nitrogen levels were less than 0.20 mg N/L in both Rock Creek and Little Rock Creek. Total phosphorus concentrations were generally at or slightly above the detection limit of 10 µg/L.

Macroinvertebrate and fish communities were apparently unaffected by the silvicultural activities. Benthic macroinvertebrate diversity, density, and taxa richness did not apparently react to silvicultural activity, Fluctuations during the study can all be explained as natural phenomena, The same is true of all creek chub populations. Although fish mobility was prohibitive in the chub's use as a water quality indicator, no reaction in terms of production was observed in response to silviculture.

BMPs proved effective in this case study. However, other silvicultural operations may impact adjacent ecosystems to a greater extent than in the Pickett State Forest case. Some practices that may require further research in Tennessee include burning as a site preparation, stream crossings, riparian canopy removal, higher precipitation, and herbicide transport to waterways.

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LARGE WOODY DEBRIS CONTRIBUTIONS FROM RIPARIAN ZONES: CURRENT KNOWLEDGE AND STUDY DESCRIPTION [1]

Craig W. Hedman and David H. Van Lear [2]

Abstract. The ecological role that riparian zones play in contributing large woody debris (LWD) to streams has been investigated in the Pacific Northwest and Northeast, but represents a major gap in knowledge of forest ecosystem functions in Southern Appalachian watersheds. Riparian zone vegetation is a source of LWD for streams which influences stream ecology and morphology. In this study, riparian zones representing a sere from early successional through old-growth forests are being investigated to obtain quantitative/qualitative baseline data regarding the attributes of Southern Appalachian riparian zones and in-stream LWD. Characterization of LWD inputs will provide needed information for forest managers, fisheries biologists, and water resource specialists as management of riparian zones becomes increasingly important in enhancing forest diversity, resource quality and productivity.

Introduction

The forest/stream interface is a zone of numerous, complex interactions important to both terrestrial and aquatic components of watershed ecosystems. The transfer of materials and energy between these areas is mediated by a riparian zone sometimes distinctive in composition and structure from upslope vegetation (Brown et al., 1978; Oliver and Hinckley 1987). Based on a functional rather than a vegetative or topographic definition, the riparian zone is the area of direct interaction between aquatic and terrestrial environments (Swanson et al., 1982; Waring and Schlesinger 1985). Ecological functions of riparian zones include: (1) supplying food for stream organisms; (2) regulating solar energy; (3) buffering nutrient and sediment inputs from upslope and upstream sources; (4) stabilizing streambanks and floodplains ; (5) regulating streamflow; and 6) contributing large woody debris (LWD) to streams (Miller 1987).

The input of LWD to streams from the surrounding forest exemplifies the complex link between terrestrial and aquatic components of forest ecosystems. LWD is an important ecological and morphological component of mountain streams. It controls routing of sediment and water through channel sys terns, defines habitat opportunities for stream organisms and serves as a substrate for in-stream biological activity (Swanson et al., 1982). LWD also forms a stepped gradient within stream channels (up to third order) which dissipates stream energy (Heede 1972). Wood eventually becomes a component of the aquatic

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food web as it is broken down by stream invertebrates and weathering. However, the primary function of LWD is related to its inherent structural characteristics which influence channel hydraulics (Bisson et al., 1987).

Background information regarding the function of mountain riparian zones as a source of LWD has been extensively documented in the West (Swanson et al., 1976,; Swanson and Lienkaemper 1978; Harmon et al., 1986; Lienkaemper and Swanson 1987) and the Northeast (Zimmerman et al., 1967; Likens and Bilby 1982; Bilby 1984). Additional information regarding LWD input rates from pristine and disturbed riparian zones is needed. Also, information concerning LWD delivery and redistribution mechanisms, quantities of LWD required to optimize stream productivity and how to manage riparian areas to provide the sizes and types of LWD needed is lacking (Lienkaemper and Swanson 1987, Miller 1987).

Bisson et al. (1987) believe there is an urgent need for controlled field experiments and long-term studies that focus on the protection of existing large woody debris in stream channels and the recruitment of new debris from the surrounding forest. On a broader scale, comprehensive ecological knowledge for streams flowing through riparian zones of all successional stages including old-growth is limited. Examination of streams flowing through old-growth forests will provide baseline reference points which can be used to compare managed stream habitats with virgin environments (Sedell and Swanson 1984; Bisson et al., 1987).

In the Southeast, LWD dynamics are poorly understood and represent a major gap in knowledge. It will therefore be necessary to first quantify and characterize loadings of LWD. Once these baseline levels are established for riparian zones in different successional stages, future research can document the relationship between LWD and productivity and diversity of aquatic systems. The current study will provide quantitative and qualitative descriptions of Southern Appalachian riparian zones and in-stream LWD.

Current Knowledge And Management Implications

Riparian zones are productive areas important for timber, fish, wildlife and water quality. In the past 10 years, the overall interest in the role and management of in-stream woody debris has increased dramatically (Bisson et al., 1987). Increased interest of natural resource professionals and the general public requires that silviculturists manipulating riparian zones recognize that their actions may affect erosion, aquatic and terrestrial productivity, stream temperature, nutrient levels, and coarse woody debris (Oliver and Hinckley 1987). According to Garland (1987), it is not sufficient to prescribe 100-ft stream buffers. The requirements of aquatic and terrestrial systems must be identified so that management practices can be tailored accordingly. With all these different roles and potential user group concerns, management objectives for riparian zones often conflict (Oliver and Hinckley 1987). Bisson et al. (1987) offer the challenge, "Can we have it both ways and realize the commercial worth of timber in the riparian zone and also maintain an adequate source of woody debris for streams?"

Before discussing management alternatives for riparian zones, let us first establish what is known about LWD originating in riparian zones of different seral stages from other regions of the country. The following points are taken from state-of-knowledge articles by Bisson et al. (1987) and Sedell and Swanson (1984).

1. Stability of debris accumulations is important for maintaining good stream habitat. Factors which contribute to stability include length, diameter, presence of branches, and root wads. Whole trees are more stable than tree fragments and length of piece relative to channel width is critical.

2. Forest management alters the composition of riparian vegetation through establishment of early successional species, and resultant debris from second-growth stands has shorter residence times in stream channels than debris from old-growth or virgin forests.

3. The majority of stream habitat in old-growth forests is created and/or maintained by LWD.

4. The input of LWD from second growth riparian zones is significantly lower than inputs from old-growth stands.

5. Although our knowledge of debris abundance in streams in managed second-growth watersheds is incomplete, there is evidence that past forest practices have resulted in a long-term decline in debris and debris-related fish habitat in small to medium size streams.

Bisson et al. (1987) described several ways to enhance the recruitment of LWD. Leaving an undisturbed buffer strip of old- growth timber will ensure a long-term supply of long, large diameter logs, but will be costly in terms of timber value forgone. Managers could selectively harvest in the riparian zone, but leave a predetermined fraction of timber to satisfy stream's habitat needs and allow LWD to enter the channel through natural processes. Timber could be harvested from the riparian zone on a double rotation basis, i.e., every 100-150 years instead of 75- to 80-year rotations (commonly used for Pacific Northwest conifers). The riparian zone could be silviculturally manipulated to maintain a relatively even delivery of LWD, while providing a mix of species. Introductions of unmerchantable trees and culls could be encouraged during harvest or midrotation activities like thinnings. Finally, use of substitute structures, like boulders and rock-filled gabions when a source of LWD is unavailable, is a possible method.

Miller (1987) believes that with intermediate levels of timber removal or a selection management approach in the riparian forest, all age classes and species diversity could be maintained. Such practices should increase biodiversity of these areas and dampen the periodicity of LWD inputs. Oliver and Hinckley (1987) point out that unveven-age silvicultural techniques are less practiced and refined than even-aged ones, and therefore uneven-age riparian zone prescriptions would have to be developed. They also suggest that riparian zones may be managed with trees at wide spacings. Such an approach would allow for rapid growth to large diameters and this may be desireable for wood utilization, wildlife habitat, and future in-stream logs.

Development of procedures that protect existing instream debris, as well as provide continued long-term supply of the proper quantity and quality of LWD, are needed. Validation of management options will require scientific testing over a wide range of stream sizes. Thorough understanding of long-term effects of forest management on stream habitat is contingent upon further research of linkages between specific riparian zone management practices and in-stream processes. These studies must go beyond postlogging surveys of habitat change and examine preplanned manipulations of debris loads and recruitment rates during actual management operations (Bisson et al., 1987).

Current Study

A stated objective of this silvicultural research conference is to present research in progress and inform the silvicultural community in a timely manner of important new ideas. By reviewing current knowledge of riparian zones in other areas of the country, we hope to stimulate further research of the status and function of riparian zones in the South. Although this study is in its early stages, we thought it important to discuss with southern foresters the implications of riparian zone management and the need to initiate research on this topic.

Study Area

The study is located in the Blue Ridge Mountain physiographic province near the common borders of North Carolina, South Carolina, and Georgia. Study sites are situated within and proximal to the Coweeta Hydrologic Laboratory near Franklin, North Carolina.

Project Objectives

* Characterize mountain riparian zones in various stages of secondary succession on the basis of vegetation and soil properties;
* Quantify volume and weight of LWD present in mountain streams;
* Identify and age LWD to determine approximate date of deposition;
* Determine relationships between seral stage and LWD;
* Evaluate the role of LWD on channel morphology and stream habitat diversity;

We hypothesize that characteristics of riparian zone vegetation and contributions of LWD to stream systems change throughout the course of plant community succession. Therefore, riparian zones representing a sere from early successional through old-growth are being studied.

Pacific Northwest studies have shown that debris loading in streams increases immediately after logging, and is followed by a rapid decline in debris abundance (Bryant 1985). Several decades may pass before LWD inputs begin to increase. In the Pacific Northwest, Grette (1985) found that an increase in LWD loading from second-growth stands was slow and occured 60 years after logging. Webster and Swank (1985) theorized that, depending on logging practices, there may be an initial increase in LWD loading from logging in the Southern Appalachians, followed by a 5- to 20-year period of reduced inputs due to the smaller size of early successional riparian zone vegetation. If conditions in the Coweeta Basin are representative of the Southern Appalachians, then the minimal amount of in-stream LWD probably occurs 20 to 30 years after logging. One goal of our study is to test the Webster and Swank model.

Summary

This paper summarizes current knowledge regarding the role of riparian zones in contributing LWD to stream systems. The majority of research on this topic has taken place in the Pacific Northwest and Northeast. Knowledge of LWD contributions by riparian zones in Southeastern watersheds is lacking. Information concerning this role is essential if riparian zones are to be wisely managed for multiple benefits. In this study, the character of Southern Appalachian riparian zones will be determined as vegetation proceeds through secondary succession to old-growth. In addition, quantitative and qualitative base-line data regarding attributes and functions of LWD in mountain streams will be evaluated.

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EFFECTIVENESS OF THREE STREAMSIDE MANAGEMENT PRACTICES IN THE CENTRAL APPALACHIANS [1]

James N. Kochenderfer and Pamela J. Edwards [2]

Abstract. The effects of three silvicultural and streamside management practices on sediment loss, water temperature, and nutrient export were evaluated on experimental watersheds in north-central West Virginia. The practices were clearcutting an 84.7-ac watershed (Fernow), mechanically site preparing a 28.6-ac watershed (Clover), and cutting a 96.4-ac watershed (South Haddix) to a 14-inch stump diameter. Initial streamside management on the Fernow watershed consisted of cutting the buffer strip lightly, followed by completely cutting the buffer strip and clearing the stream channel of all slash and debris 2 years later. The buffer strip was uncut on Clover, but heavily cut on South Haddix. Average buffer strip width was 66 ft on the Fernow and Clover watersheds and 160 ft on South Haddix. No silvicultural treatment significantly increased sediment yields on any of the watersheds. Similarly, the treatments had little effect on stream water chemistry, though electrical conductivity and nitrate-N concentrations increased slightly on all three watersheds. Water temperatures did not increase significantly when the streamside zones were only partially cut, but complete clearing along the Fernow stream channel caused a large temperature increase. Minor effects due to treatment are attributed to the moderating influences of properly managed streamside zones and careful timber harvesting and site preparation practices.

Introduction

Land managers long have realized that streamside areas are critical for maintaining high-quality water, so management practices in these areas normally are modified to protect both soil and water. A strip of undisturbed land, called a filter strip or buffer strip, is routinely left between water courses and disturbed areas (for example, roads or harvested areas) to trap and filter out.sediments before they reach streams. Most guidelines for erosion control on forest land recommend filter strip widths originated by Trimble and Sartz (1957), based mainly on the steepness of land between roads and streams. A minimum width of 100 ft is often recommended (Kochenderfer 1970). Cutting is modified in streamside zones to maintain shade, thus, preventing stream temperature increases and forestalling stream bank disturbance. Filter strips usually encompass shade strips and riparian boundaries in mountainous areas. More recently, it has been recognized that trees in streamside areas provide woody debris that helps stabilize stream channels (DeBano and Heede 1987) and promote beneficial biological processes within streams (Bilby 1984). Streamside areas also can act as a "sink" for nutrients

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discharged from surrounding disturbed areas (Lowrance et al., 1984).

The objective of this paper is to evaluate the effectiveness of three silvicultural and streamside management practices for controlling sediment loss, nutrient export, and water temperature in north-central West Virginia.

He thods

Watershed Descriptions and Treatments

One control and three treatment watersheds were used for the study. They are located in the unglaciated Allegheny Plateau of north-central West Virginia, within a 10-mi radius of the town of Parsons. The region is characterized by steep mountains and narrow valleys. Annual precipitation averages 57 inches on all the watersheds and is distributed relatively evenly between dormant and growing seasons. Some pertinent watershed characteristics are listed in Table 1.

Table 1. Some characteristics of the treated watersheds.

Watershed	Total area	Buffer strip area	Average[1] buffer strip width	Channel length	Channel width	Average annual discharge
	---- ac -----		------------- ft	--------------		-- cfs --
Fernow	84.7	7.4	66	2994	6.4	0.26
Cl over	28.6	3.5	66	861	2.8	0.06
S. Haddix	96.4	25.6	160	3436	5.7	0.31

[1] Along each side of the perennial stream channel.

The Fernow watershed has a southern aspect and an average slope of 20 percent. The predominant soil is Calvin channery silt loam (loamy-skeletal, mixed mesic Typic Dystrochrepts) underlain with fractured sandstone and shale of the Hampshire formation (Losche and Beverage 1967). In 1969, before treatment, it supported a vigorous 65-year-old hardwood stand. Common tree species were yellow-poplar (Liriodendron tulipifera L.), black cherry (Prunus serotina Ehrh.), American beech (Fagus grandifolia Ehrh.), and northern red oak (Quercus rubra L.). Basal area averaged 95 ft^2 ac^{-1} for trees 5-inch dbh and larger.

Treatment of the Fernow watershed is described in detail by Patric (1980). In brief, it was clearcut to l-inch dbh between July 1969 and May 1970 except for a 7.4-ac buffer strip along the stream channel. A light selection cut was performed in the buffer strip, but the stream channel remained completely shaded. Machinery was not permitted in the buffer strip;

trees were winched up and away from the stream channel. No roads or landings were located closer than 66 ft to the stream channel. In November 1972 the buffer strip was clearcut, and the streamside area (8 ft on both sides of the channel) and stream channel were cleared manually with chainsaws of all debris, fully exposing the stream and its banks to sunlight. Both logging slash and woody debris naturally deposited in the stream were removed; consequently, this operation went beyond normal slash removal. The channel, well armored with sandstone rock, and stream banks were completely reshaded with hardwood regeneration by 1977.

The Clover watershed was part of a mountain farm for many years until 1930 (Lima and Patric 1978). It has a southern aspect and an average slope of 25 percent. The predominant soil is the same as that described for the Fernow watershed. After farming ended, poor-quality hardwoods naturally revegetated the watershed, dominated by red maple (Acer rubrum L.), sassafras (Sassafras albidum (Nutt.)), various species of oak (Quercus spp.), and hickory (Carya spp.). Average basal area in 1983 was 70.0 $ft^2 ac^{-1}$ for trees larger than 1-inch dbh. Evidence of past soil erosion was visible in the silted stream channel; it noticeably lacked rock and appeared to have active bank erosion.

A "minimum-standard" access road as described by Kochenderfer et al. (1984) was constructed in the Clover watershed in June 1983. Additional skidroads, suitable for dry weather use by pickup trucks, also were constructed. Approximately 25 ac were clearcut by November 1983, then subjected to a mechanical site preparation treatment as described by Kochenderfer and Helvey (1989). The brush was windrowed by a D7F tractor equipped with a root rake, mostly along the contour and around the perimeter of the cut area. Roads were used for windrow locations when possible. A 3.5-ac buffer zone along the stream was undisturbed. A steep (30+ percent) 3-ac area in the northwest corner of the watershed was not mechanically site prepared.

The South Haddix watershed has a southern aspect and an average slope of 40 percent. The vegetation on it has not been disturbed since the 1930s. In 1986, before treatment, it supported a mixed-aged stand composed of various species of oak and hickory, and yellow-poplar, which are more xeric than vegetation on the other watersheds. Approximately one-third of the watershed contains a dense understory of rhododendron (Rhododendron maximum L.). Average basal area was 92 $ft^2 ac^{-1}$ in trees 6-inch dbh and larger. This catchment is underlain with interbedded shale, siltstone, and sandstone of the Chemung geologic formation. The predominant soil is Berks channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts). The stream channel is covered with sandstone rock, and its banks are protected with vegetation. Channel stability appears to be intermediate between the Clover and Fernow watersheds.

In the South Haddix watershed, the complete road system was designed and constructed before logging began. It included three miles of skidroad and 0.9 mi of "minimum-standard" truck road. Logging by wheeled skidders was intermittent between May 1986 and February 1987. The entire watershed except for a 4-ac area at the head of the watershed was cut to a 14-inch stump diameter, a commonly used practice on private land in this area.

Cutting was permitted in the buffer zone, but the stream channel remained shaded by the standing vegetation and logging debris. No roads or machinery were permitted in the buffer strip. Trees near the skidroads were winched from the buffer strip using a skidder; those further from skidroads were winched out by a D-4 dozer equipped with 200 ft of 5/8-inch wire rope. A total of 513,000 bf of sawtimber was harvested, reducing basal area from 92 $ft^2 ac^{-1}$ to 50 $ft^2 ac^{-1}$ for trees of 6-inch dbh and larger.

An unmanaged watershed was used as a control, against which treatment results were compared. It faces southeast and has an average slope of 24 percent. This watershed has remained undisturbed since about 1905 when it was heavily cut; however, dead American chestnut [Castanea dentata (Marsh.) Borkh.] was salvaged during the 1940s. Predominant soils, geology, and vegetation are similar to those on the other three watersheds. The stream is fully shaded by both standing vegetation and woody debris.

Streamflow and Sediment

Streamflow was measured with 120° V-notch weirs on the Fernow, Clover, and control watersheds, and with a 3-ft H-type flume on the South Haddix watershed. Each stream gaging site was equipped with an FW-1 water-level recorder. Sediment samples on the Clover and South Haddix watersheds were collected with Coshocton wheels, which diverted 0.5 percent of the total flow into a 600-gal storage tank. Two samples from each tank were taken weekly during baseflow and before they overflowed during storms. Tank contents were agitated vigorously while two 0.2 gal samples were collected from a spigot at the tank base. Samples were vacuum-filtered in the laboratory to determine sediment concentrations (ppm). Suspended sediment yield (lb ac^{-1}) was computed by multiplying measured streamflow volume for the sampling period times average sediment concentration of the two tank samples. These results were summed to obtain annual suspended sediment yield.

Bedload at the Clover, South Haddix, and control watershed gaging stations was trapped in a box and measured periodically to determine its volume (ft^3). Subsamples were oven-dried to determine average bulk density (lb ft^{-3}). Sediment volume multiplied by average dry bulk density gave sediment weight in each box. The sum of suspended sediment and bedload provided annual sediment export from each watershed.

Sediment yields from the Fernow watershed were estimated from weir pond deposits (Kochenderfer and Helvey 1984). When the weir pond was cleaned, the volume of trapped material was recorded. Measurements have indicated that the oven-dry weight of the trapped material has averaged about 53 lb ft^{-3}. This conversion factor was used to estimate weight of deposited material from volume measurements. By measuring suspended sediment using a 10.5 x 10.5 x 6-ft sediment box, it was determined that only 25 percent of the sediment actually produced was trapped in the weir ponds. Consequently, that factor was used when estimating total sediment yield from measured deposits in the weir pond.

Sediment exports from all three sites are presented using a Nov. 1-Oct. 30 water year (for example, the period from November 1, 1985-October 30, 1986 is water year 1986). Sediment water years were defined by this interval because all of the cutting experiments for sediment were designed specifically for November-October water years.

Stream Water Temperature and Chemistry

A maximum/minimum thermometer was placed in the stream just above the gaging station in each watershed, and readings were recorded weekly or bi-weekly. During some periods the streams dried up, and the water level did not cover the thermometers. If the thermometer was not submerged at the time of the site visit, no readings were recorded.

Stream water from each watershed was grab sampled at weekly or biweekly intervals. These samples were analyzed for electrical conductivity (µS cm^{-1}) using a Wheatstone bridge and for nitrate nitrogen (mg L^{-1}) using the Hach Nitra Ver IV'" method (Hach Chemical Co. 1977) before 1981 and ion chromatography thereafter. Stream chemistry is presented using a May 1-April 30 water year (for example, the period from May 1, 1985-April 30, 1986 is water year 1985). This water year designation best describes the hydrologic and chemical behavior of these watersheds.

Nitrate loadings (lb ac^{-1}) for each water year were calculated by multiplying average annual nitrate nitrogen concentrations times flow (csm) and the appropriate conversion factor to obtain the proper units. Conductivity values simply were averaged by water year.

Results And Discussion

Sediment Loss

Annual sediment yield from the Fernow watershed averaged 238 lb ac^{-1} before the clearcutting treatment in 1969. An intensive selection cut in trees larger than 5-inch dbh had been performed in 1957-58 and 1963, with an additional 5.6-ac in the upper portion of the watershed patch cut in 1963. Carefully located bulldozed skidroads occupied less than 1 percent of the watershed area as a result of these operations. However, some logs were skidded across the main stream channel on a wooden bridge with rather steep approaches which probably resulted in sediment reaching the stream channel. This history might explain why sediment export from this watershed was considerably higher than the nearby control watershed before the clearcutting treatment. Sediment yield averaged 280 lb ac^{-1} in 1969 and 1970 following the clearcutting treatment, but fell to an average of 127 lb ac^{-1} during the 1971-73 period which included the November 1972 channel clearing. Sediment export had decreased to an average of 65 lb ac^{-1} between 1974-85.

Annual sediment yields are shown in Figure 1 for the control, Clover and South Haddix watersheds. The Clover watershed, with its silted stream channel attributable to its farming history, has consistently yielded more sediment than the other watersheds. Annual sediment yields before the site preparation treatment in 1983 averaged 253 lb ac^{-1}. Annual sediment yields for four years after treatment averaged 344 lb ac^{-1}. This average includes a large loss in water year 1986 of 521 lb ac^{-1} caused by a 5-inch storm with an estimated recurrence interval of 100+ years. Al though average annual sediment yields from Clover were greater after site preparation,

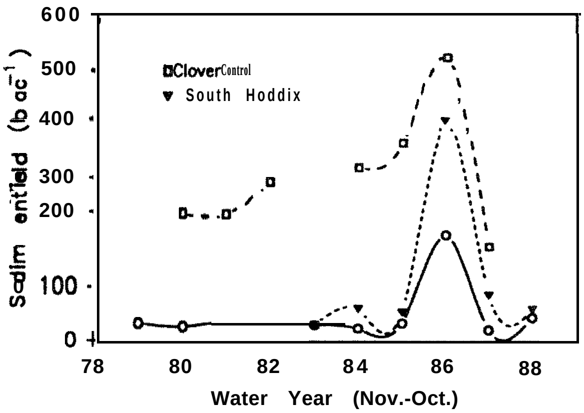

Figure 1. Annual sediment yields for the control, Clover, and South Haddix watersheds.

Kochenderfer and Helvey (1989) concluded that the increases were not significant at the 95-percent probability level. They attributed the following factors for preventing larger increases. First, root raking was done carefully to minimize soil disturbance, and the slash was windrowed on the slope. Second, regrowth of vegetation on the treated area was very rapid. The percentage of bare soil exposed decreased from 45 percent after site preparation to 15 percent at the end of the first growing season. Third, a 3.5-ac buffer strip was left around the stream. This untreated area extended 66 ft on each side of the stream and encompassed the extensions of the stream channel that contained live water during normal storm events.

Annual sediment yields on South Haddix and the control averaged 48 lb ac^{-1} and 29 lb ac^{-1}, respectively, before the treatment in 1986 and 182 lb ac^{-1} and 86 lb ac^{-1}, respectively, after treatment. Sediment yields increased on both watersheds due to the large 100+ year storm in November 1985 that caused widespread flooding. Sediment yields during that flood year were 403 lb ac^{-1} and 195 lb ac^{-1}, respectively (Fig. 1). Average annual sediment yields between South Haddix and the control three years before treatment differed by 19 lb ac^{-1}; after treatment the difference was 96 lb ac^{-1}. Sediment yields were increased on the South Haddix watershed in 1986-87, but dropped to 58 lb ac^{-1} by 1988.

In general, the treatments had a minor effect on sediment yields. With the exception of the flood during sediment water year 1986, sediment yields on the South Haddix watershed were within the 0.05 to 0.10 ton ac^{-1} yr^{-1} range for natural geologic erosion in eastern forest land (Patric 1976). Sediment yields on the Fernow watershed were higher than the control even before cutting, probably due to the early treatments during the late 1950s to early 1960s. Clearcutting temporarily increased sediment exports by about 15 percent. The Clover watershed, with its silted stream channel attributed to its past farming history, yielded more sediment throughout the measurement period. Even in the record flood year, sediment yields barely exceeded the 500 lb ac^{-1} yr^{-1} upper limit considered acceptable for eastern forested land (Patric et al., 1984).

Temoerature

In the central Appalachians, temperatures most harmful to aquatic organisms occur during the summer and early fall, especially when streamflow is lowest. As such, only weekly maximum and minimum temperatures for the growing season (May 1-October 31) were examined. Embody (1921) and Kendall (1924) determined 74.8°F as the temperature at which trout can survive only temporary exposure. We have designated this value as the aquatic sensitivity threshold value.

Data were not recorded when the thermometers were not submerged in stream water during the visit. Exposure generally occurred during the hottest and driest periods. Some data that were recorded may be suspect since the thermometer may have been submerged during the site visit but not for the entire monitoring period. The combination of these problems invalidates statistical analyses, so only general comparisons were made for temperature. Table 2 shows mean and maximum growing season stream temperatures for the treated and control watersheds. Calibration data immediately before treatment were unavailable for temperature on the Clover watershed; consequently, pretreatment data from 1960-65 were substituted for that period.

Lee and Samuel (1976) concluded that clearcutting had a statistically nonsignificant effect on stream temperatures on the Fernow watershed when the buffer strip was left intact. Only a slight temperature increase, if any, occurred in the Fernow stream following the clearcutting and light selection cut in the buffer strip in 1969-70. However, a large temperature increase was recorded during the three years following buffer strip cutting and stream channel clearing. The maximum increase occurred during the first year, declining slowly and reaching pretreatment temperatures in 1976. During the first year peaks, the maximum temperatures increased to as high as 76°F for 3 weeks. In fact, the aquatic sensitivity threshold was exceeded during 4 weeks. Temperatures above 72°F but less than 74.8°F were reached an additional five times. During the second year, the aquatic sensitivity threshold was not exceeded but temperatures of 72°F or higher occurred during 3 weeks in July.

A 71°F peak in the Fernow stream in 1976 is believed to result from an unsubmerged thermometer or a period of extremely low flow with correspondingly high air temperatures. In the latter case, the high air temperature for the week in question was 85°F, occurring simultaneously on a day of very low flow (0.04 csm). Thus, the buffer strip removal and stream clearing probably had little effect in the fourth post-treatment year. Patric (1980) concluded that channel shading was sufficient by 1977 to return stream temperatures to pretreatment levels.

Because the buffer strip in the Clover watershed was not cut, no temperature effects were expected, and none occurred (Kochenderfer and Helvey 1989). However, in 1984, a peak of 68°F was recorded. This maximum did not correspond to low flows, so it may have been caused by advective heat from the adjacent clearcut areas. Stream warming, even during extremely low flows, was not sufficient to reach the aquatic sensitivity threshold.

Partial cutting in the South Haddix buffer strip had little or no effect on stream temperatures. This stream consistently has high growing season temperatures (Table 2) though channel area, average flow, and aspect

Table 2. Growing season stream temperature comparisons for the control and treated watersheds during calibration and treatment periods.

Temperature variable	Control	Fernow	Control	Clover	Control	S. Haddix
	---	---	---	°F ---	---	---
			Calibration period			
Overall mean[1]	55.2	56.1	55.1	55.0	56.8	57.9
Highest mean	63.0	64.0	63.0	61.5	66.5	67.0
Mean maximum[2]	58.8	60.0	59.4	60.4	60.2	65.0
Absolute maximum	67.0	70.0	67.0	66.0	68.0	72.0
			Treatment period			
Overall mean[1]	55.7	57.7	56.8	58.0	56.9	58.0
Highest mean	64.0	70.5	66.5	67.0	66.0	70.5
Mean maximum[2]	59.1	63.0	61.1	62.9	61.5	63.5
Absolute maximum	68.0	76.0	72.0	70.0	72.0	78.0
Number of weeks above 74.8°F		4		0		1

[1] Overall and highest temperature means were determined by averaging the weekly maximum and minimum temperatures.

[2] Mean and absolute temperature maximums were determined using only weekly maximums.

are very similar to the Fernow stream. However, it is considered a drier site from a timber standpoint, having a higher percentage of oak and hickory species growing on it than the other watersheds. The dense understory of rhododendron that was prevalent along much of the stream channel may have helped prevent temperature increases. A maximum peak of 78°F in 1988 occurred during a week of extremely low flows, with an average daily flow of 0.049 csm and a record high air temperature of 99°F. Thus, the thermometer may not have been submerged when the 78°F measurement was recorded. And if it was submerged, the air temperature apparently was a significant factor in controlling water temperature.

Results from these watersheds indicate that relatively narrow buffer strips are effective in maintaining stream temperatures below the aquatic sensitivity threshold. Since these watersheds all faced south, protection also should be expected on watersheds with other aspects. During the growing season, when flows are extremely low, air temperatures may influence stream temperature more strongly than inflowing water, and thus, warm streams faster than expected. However, through most of the growing season, stream temperature combines the thermal influences of ambient air and inflowing water. During moderate to high flows, the temperature of influent water would dominate stream temperatures. Thus, on larger streams that support fisheries (for example, streams in ≥1000-ac watersheds), warming caused by streamside management practices will be dampened or nonexistent because influent water controls stream temperature.

Stream Chemistry

Electrical conductivity and nitrate nitrogen are the only chemical parameters discussed in this paper. Electrical conductivity is an index-of total dissolved solids, describing the combined behavior of all dissolved chemical species in stream water. Nitrate nitrogen was determined because it is one of the most important ions relating to soil productivity and water quality.

The average annual conductivities for streams draining the treatment and control watersheds are shown in Figure 2. To determine whether the harvesting practices affected conductivity, a graphical comparison with the control and a statistical comparison between observed and predicted outputs were performed for the Fernow watershed. Only a graphical comparison was used for the Clover and South Haddix watersheds because of the limited data available.

A regression equation was developed to predict annual average conductivity of the Fernow watershed from conductivity of the control during the calibration period. This equation then was used to predict average annual conductivities had there been no cutting treatment. Differences between observed and predicted conductivities (Table 3) are the effect of clearcutting.

The differences for the Fernow watershed show that the observed conductivity was less than predicted, a result we believe largely due to behavior of the control. Conductivity on the control increased somewhat during the post-treatment period (Fig. 2) (Edwards and Helvey 1991) probably resulting in abnormally high predictions. Thus, this regression analysis may tell more about the control than the Fernow watershed.

However, neither clearcutting in 1969 nor cutting the buffer strip and clearing the channel in 1972-73 caused much, if any, change in conductivity of the Fernow stream (Fig. 2). A larger response may have occurred when the watershed was clearcut and the buffer strip was lightly cut. The area clearcut was much larger and there was some disturbance in the buffer strip, so nutrient exports to stream water apparently were greater for the first part of the treatment.

Conductivity for South Haddix was higher than for the control even during the calibration period (Fig. 2). On South Haddix, it averaged 29.5 $\mu S\ cm^{-1}$ while only 21.3 $\mu S\ cm^{-1}$ on the control during the 3 years before treatment. Conductivity increased 3.6 $\mu S\ cm^{-1}$ in 1987, to 33.1 $\mu S\ cm^{-1}$ the first year after treatment (Fig. 2), a 12 percent increase. Conductivity returned almost to pretreatment levels one year after timber harvesting.

Table 3. Average annual conductivities on the Femow and control watersheds.

Water year	Control observed	Fernow observed	Fernow[1] predicted	Difference
	----------	---------- $\mu S\ cm^{-1}$	----------	----------
1969	16.4	15.7	15.4	0.3
1970	16.5	16.4	15.5	0.9
1971	17.7	17.5	16.3	1.2
1972	17.8	16.1	16.4	-0.3
1973	18.1	16.3	16.5	-0.2
1974	18.3	15.7	16.7	-1.0
1975	19.2	15.6	17.3	-1.7
1976	20.3	16.2	18.0	-1.8
1977	19.5	16.5	17.5	-1.0
1978	19.4	16.1	17.4	-1.3
1979	19.0	16.0	17.1	-1.1
1980	21.4	18.0	18.7	-0.7
1981	22.6	17.1	19.5	-2.4

[1] Regression equation: Y = 4.618 + 0.659X (correlation coefficient: R^2 = 0.71); calibration period, water years 1965-68.

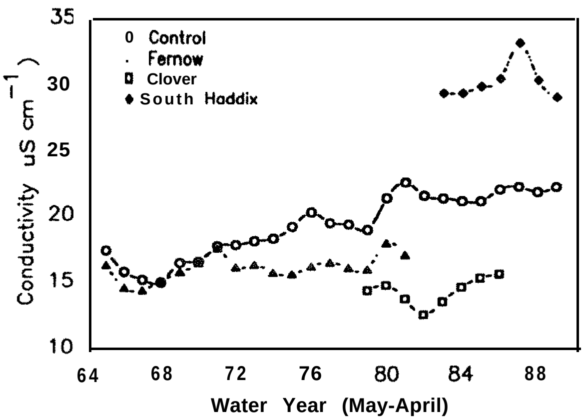

Figure 2. Average annual conductivities for treatment and control watersheds.

Because of the combination of the relatively small conductivity increase and the short time of the increase, we do not consider the effect to be significant.

On the Clover watershed, conductivity increased after the site preparation treatment (Fig. 2), rising from 12.6 to to 15.7 $\mu S\ cm^{-1}$. Because of the confounding effects of a new treatment on Clover beginning in April 1987, the duration of influence of the cutting and site preparation cannot be determined. However, we believe that the conductivity increase was not chemically or biologically significant.

Regression techniques were used to compare annual predicted outputs (lb ac^{-1}) to observed outputs of nitrate nitrogen for South Haddix. Graphical comparisons between South Haddix and the control also are given. A regression could not be developed for the Fernow watershed because it had only 1 year of calibration data, nor for Clover because it had only two years of calibration data with a very low R^2 value ((0.005). For these latter two watersheds, graphical comparisons are shown.

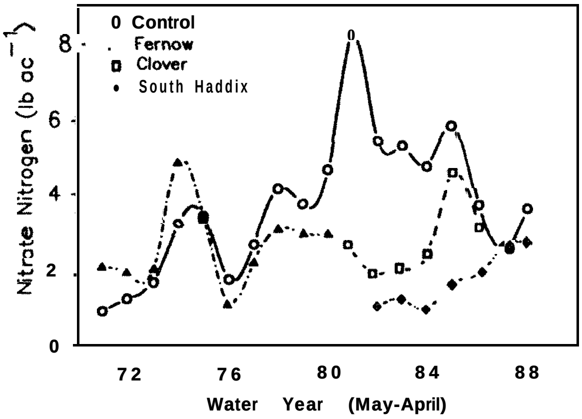

Figure 3. Annual. nitrate nitrogen outputs for treatment and control watersheds.

With no pre-clearcutting data available for the Fernow watershed, it was impossible to make valid conclusions about its nitrate nitrogen response. However, close tracking between it and the control (Fig. 3), combined with the longer term conductivity results, suggests that cutting had only a slight effect. The Fernow output dropped below the control in 1975. This drop may be due to a natural return to pretreatment levels, but more likely it resulted from removal of all nitrogen-containing debris in and around the stream channel. Thus, both the clearcutting and stream channel clearing affected nitrate outputs, but in opposite ways. Note that nitrate nitrogen increases due to cutting were small, only 0.9-1.8 lb ac^{-1} yr^{-1}, representing only a tiny portion of the nitrate pool in the watershed.

If clearcutting and site preparation had an effect on the Clover watershed, it did not occur until water year 1985. However, that year's peak was due only partially to increased concentration. A significant part of it was due to the greater flow for that year, resulting primarily from the record flood in November 1985. Without the flood, the 1985 peak is estimated to have been about 0.4 lb ac^{-1} lower than observed.

The buffer strip was not mechanically disturbed and slopes adjacent to the stream are not steep, so the nitrate nitrogen increase is attributed to decreased vegetative uptake immediately following clearcutting and by increased nitrification resulting from soil warming. Increases at other harvested sites have been reported elsewhere (Hornbeck et al., 1987). The downward trend in 1986 is the expected response as revegetation rapidly assimilates nitrogen.

The observed nitrate nitrogen outputs for South Haddix (Table 4) were greater than those predicted for all monitored post-treatment years. However, only very small outputs were predicted because the control outputs averaged 1.99 lb ac^{-1} lower during the post-treatment period than during calibration. Thus, the difference between predicted and observed output for South Haddix may be an artifact of the behavior of the control watershed.

A small increase in nitrate nitrogen output, about 1 lb ac^{-1}, followed timber harvesting (Fig. 3). The rate of increase declined during 1988. This increase, which explains at least part of the conductivity increase, is attributed to the heavy cut that removed 46 percent of the basal area over most of the watershed, including the buffer strip.

Table 4. Nitrate nitrogen exports from the South Haddix watershed.

Water year	Control observed	South Haddix observed	South Haddix[1] predicted	Difference
		lb ac^{-1}		
1986	3.71	1.90	0.32	1.58
1987	2.55	2.64	0.00	2.64
1988	3.60	2.71	0.26	2.45

[1] Regression equation: Y = -1.76 + 0.56X (correlation coefficient, R^2 = 0.72); calibration period, water years 1982-85.

Conclusion

Treatments had only minor effects on sediment yield from all watersheds. Adequate filter strips and lack of road building and machinery in streamside zones minimized soil erosion and sediment movement adjacent to the streams. The buffer strips also prevented stream temperature increases. However, on the Fernow watershed temperatures increased to a maximum of 76°F for 3 weeks after cutting the buffer strip and clearing the stream channel. Small nitrate exports accompanied all three treatments, but were temporary and represented only a small portion of the nitrate pools. These minimal effects due to treatment are attributed to the moderating influences that resulted from protecting the streamside zones and careful timber harvesting and site preparation practices.

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LOW-IMPACT HARVESTING SYSTEMS FOR WET SITES [1]

Ben D. Jackson and Bryce J. Stokes [2]

Abstract. Harvesting timber on wet sites has always proposed a problem to the logger and the landowner. Various methods have been used to economically harvest such sites. A summary of commonly-used felling, processing, and extraction machines are presented. The forest community is aware that new, innovative methods must be developed which cause little site disturbance. Research priorities are identified that are required to understand the options and to properly select and apply the technology as it is developed. Several new alternatives have been identified here.

Introduction

Wet sites pose problems to conventional logging operations and can result in high costs and residual site damage. From a logger's point of view, wet sites impact the operational efficiency, increase costs, and reduce profits. From a landowner, forest management and an environmental perspective, unacceptable residual site impacts can cause degradation to site productivity, water quality, and aesthetics (McKee and Haselton 1989; Aust et al., 1988).

The forest industry and loggers realize the value of minimizing site damage and are looking for low-impact harvesting systems. Several states have implemented voluntary guidelines for timber harvesting (Anonymous 1987, Ice 1989). There are specific regulations for forestry activities that pertain to wet sites (EPA 1988, Haines et al., 1988). Today's harvesting systems must not only be able to physically operate and be economically feasible, but also must be socially acceptable. Again, without quantifying acceptable performance criteria, systems should consist of machines that minimize rutting and compaction and need less roadbuilding than conventional systems.

In this paper we will not endeavor to define or characterize wet sites or quantify site damage. However, a technical solution is needed to insure that wet sites are maintained for wood production as well as their other multiple uses. The objective of this paper is to review current harvesting equipment and systems used on wet sites and to introduce new and innovative alternatives to conventional operations.

Current Technology

Equipment and logging engineers and manufacturers have been concerned with tractive effort or mobility. If a machine could not operate effectively, then logging became an economic failure. Most current technology is based on having

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sufficient trafficability to traverse difficult, wet sites and maintain production (Hassan 1977, Hassan and Sirois 1984).

The American Pulpwood Association conducted a survey of wetland loggers in 1986 in the Southeast (Stokes 1988). Summary results concluded that over half of the felling was mechanized and that 96 percent of the wood was extracted by skidding (50 percent used rubber-tired skidders only). In this same report, the author evaluated eight harvesting systems that specialized in wet site wood removal. Five of the systems used rubber-tired skidding. The other three systems used tracked machines for skidding.

Jackson (1990) surveyed loggers operating in the Mississippi River delta. Delta loggers were a less mechanized than those loggers in the Southeast. Almost 90 percent used chainsaw felling only. However, 98 percent used rubber-tired skidders. Some of the river delta loggers used crawler tractors and forwarders in addition to the rubber-tired skidders.

Chainsaws are used to fell much of the timber on wet sites. The reasons are the high cost and impossibility of operating conventional felling machines on such difficult sites. Carriers for conventional machines may not work well in very wet conditions and may cause a significant amount of soil and drainage damage. A few operations have modified rubber-tired carriers with wide or dual tires. Although these modifications do increase mobility, there still may be a significant amount of visible damage to the site.

In areas where a predominant amount of year-round logging involved wet sites, mechanical felling has been accomplished with tracked felling machines. Most of these machines are tracked, swing feller-bunchers whose carriers can work more efficiently on poor conditions.

A simple list of alternatives for extracting wood from wet sites would include rubber-tired skidding at the top. This has been the most cost-effective wood removal method to date. The cable skidder is able to operate under extremely difficult conditions, but can have low production and requires the operator to get off and on the machine to hook to the logs. The grapple skidder will be used as long as possible before using cable skidders, which will be used before accepting an alternative. A grapple skidder is much more productive if it has the mobility since the operator can stay in the enclosed cab.

Specialize tire options have evolved to meet the demands of low-cost skidding under wet conditions. Most recently skidders have been equipped with dual tires to increase performance (Koger et al., 1984). The dual tire combination has proven to be a cost-effective alternative, giving the contractor some flexibility to adapt quickly to wet sites and wet seasons. Such equipped skidders may be able to work in harsh conditions, but still may leave the site with high levels of disturbance. Such capabilities might even be allowing loggers to work beyond acceptable ground condition limits.

Another approach is the use of wide tires (Mellgren and Heidersdorf 1984). Several studies have shown the benefits of using wide tires for better 'flotation. Hatchell (1971) suggested that wide tires can reduce soil compaction and disturbance. Porter (1984) reported the advantages, in wet site applications, as having access to more timber, decreasing soil damage, and reducing damage to the residual stand. Listed disadvantages were high costs, reduced reliability, loss of maneuverability, and more maintenance. Over time, the usually operated tire width has changed from >34 inches to many operations using 43- or 44-inch-wide tires in the southern coastal area. Wider tire widths are now becoming acceptable in the South.

One option that combines the advantages of cable skidding and grapple skidding is the cable-grapple attachment for rubber-tired skidders (Stokes and Rawlins 1989). Cable-grapple skidders can operate more effectively on wet sites because of their capability of dropping the load after stalling, driving forward, and re-winching the load. Like a hydraulic grapple, the operator can secure and release a load without leaving the cab. Although slightly higher costs are associated with the concept as compared to hydraulic grapple skidding, the advantages outweigh the costs on extremely wet sites. This is old technology that has had limited acceptance in the South. There is much potential for using this concept in wet sites.

Other alternatives are track skidding; these include rigid steel track, flexible steel track, and flexible rubber track. Advantages of track skidders are lower ground pressure and higher traction than conventional rubber-tired skidders. Historically these options have been relatively expensive to purchase and maintain. They are only used in the worst-case scenario.

Rigid steel-track carriers, such as crawler tractors, use a towed arch to support the load or have an arch mounted on the machine. The use of wide (LPG-low ground pressure) tracks reduces the average unloaded ground pressure to less than 5 psi. Rigid-track systems have highly localized and high rear ground pressures. In the 1970s, flexible track machines were designed for wet site applications. The technology was adapted from the military. In theory, the top of the track is tensioned so that the bottom of the track can flex and conform to the ground profile. Again, they gave the mobility required, but were quite expensive to own and operate. Many were pushed past their capabilities and spiraling costs forced the use of other options such as skidders with the wide tires. The flexible rubber-belted track carriers had a high track area to weight ratio. They eventually became too expensive to maintain and operate.

Large, six-wheel drive, wide-tire forwarders have been introduced in wet area logging (Jackson et al. , 1990). The concept has shown that such machines working in combination with grapple skidders, feller-bunchers, and in-woods loaders can significantly reduce the number of woods roads needed, and can make logging feasible where conventional systems cannot operate. The forwarder is used for wood transport to the roadside while the other machines are used for processing and short movement of cut trees to the in-woods loader.

Cable systems have been used on a very limited basis. The primary advantage of cable yarding is reduced site impacts. Disadvantages are higher costs and specialization of the operation. Usually such systems were home built and had a short tower or pole. Some systems are basically ground cabling systems since no effort is made to lift the logs. At tempts at using these systems have resulted in the incorporation of cones and sleds to propel the logs over stumps.

Another option that has had acceptance, although it can be very costly, is using helicopters (Willingham 1989). This system gives the least amount of impact except from the building of decks and roads. It may be cost effective in certain situations, but it is not the answer to all problems of harvesting wet sites. Helicopter logging has been commercially feasible in harvesting large stands of high-value baldcypress (Taxodium spp.).

Research Needs

At this point, it would be beneficial to briefly identify some research needs for harvesting systems that operate on wet sites. The overall research objective is to minimize environmental impacts while maintaining an economically feasible operation. New felling methods need to be integrated with the extraction methods. Wood removal options may be restricted depending on the felling function. Chainsaw workers need to be replaced with mechanical systems. Processing needs to be mechanical and to take place at the stump if possible. Such improvements will make low-impact extraction a reality.

Research is needed to develop environmentally sensitive extraction and transportation alternatives to current methods, with an emphasis on preserving site quality. The remainder of this paper will address these two areas.

Innovative Alternatives

There are several alternatives for low-impact harvesting systems that currently exist in various levels of development or implementation. Some are only concepts, but many are used operationally, but on a limited basis, in other areas.

Mechanized felling can be done by swing feller-bunchers on tracks as described. Such machines, although costly, reduce disturbance by limiting the amount of travel on the site and through the use of wide tracks. In extremely wet sites, mats can be used to increase feller-buncher mobility and reduce site disturbance. New felling technology includes lightweight, long reaching machines that combine high production with little disturbance. A grapple-saw concept would increase the flexibility of the feller-buncher. It would reduce the weight on the end of the boom and allow the felling machine to perform limited bucking and topping. Such a machine can cut the trees, cut off the tops, and some of the larger limbs, buck logs, and pile stems. Integrating limited processing and piling into the felling function can reduce subsequent extraction impacts. This concept will be tested in the near future.

Much research has been concentrated on wood extraction. Wide tires on skidders have been and will continue to be an important option. Recently, 50- and 68-inch-wide tires have been tried in the South. Such tires can develop pressure about 3 psi on the soil and are still relatively maneuverable. However, they are quite expensive. Mellgren and Heidersdorf (1984) reported several advantages of extra-wide tires including productivity increases, fuel savings, ground disturbance reductions, less soil compaction, smaller machine requirements, smoother ride, improved stability, and increased access to timber. Disadvantages include high price, reduced maneuverability, and specialized repair and maintenance equipment.

Flexible-tracked skidders are being reintroduced in the markets. New design changes supposedly decrease operating costs to the point that such machines may be cost effective.

Several manufacturers are marketing large forwarders that are capable of moving tree-length material. Wide-tired forwarders in eastern Canada have been proven to have increased access to wood without roadwork, improved stability, safety, and comfort. They permit wet season logging, require less maintenance and have greater productivity because the machine stays on top of the ground, and reduce, if not almost eliminate, residual damage to the site (Griffin 1989). With 43-inch-wide tires, the machine has a loaded psi of 6.5 and a gross weight of almost 21 tons. This type of machine has exceptional value in long-distance wood movement. Large payloads reduce the number of passes required on the same trail.

Clambunk skidders have been used successfully on steep slopes and in the marsh lands of Canada (Mellgren and Heidersdorf 1984). The clambunk skidder has a loaded psi of 4.8 when using 68-inch tires and 7.4 psi for the 44-inch-wide tires.

Table 1. Summary of extraction alternatives.

Machine	Tires/tracks	Tire bearing/psi	Price[1]
	(inch)		($)
Cable skidder	43	6.0	107,000
Cable skidder	23, dual	5.5	97,000
Grapple skidder	43	7.0	110,000
Grapple skidder	68	3.0	142,000
FMC 220 CA	22, flex tracks	8.5	---
D5H cable crawler	32, rigid tracks	7.0	170,000
ARDCO forwarder	43	7.0	139,000
TJ forwarder	43	6.5	100,000
ARDCO clambunk	44	7.5	280,000
ARDCC clambunk	68	5.0	310,000

[1] Listed price, FOB.

Table 1 shows a summary of some ground-based extraction alternatives, Published tire pressures (psi) from manufacturers were used where possible or derived based on several assumptions. These are static pressures and will be different depending on actual load size and soil penetration. Even though the summary does not make a relative comparison of alternatives, generally it takes about three skidders to match the production of large capacity forwarders and clambunk skidders.

The proper cable system may be a solution to utilizing wood from wet sites without impacting the sites. The secret may be in giving the logs high lift, even to the point of keeping them completely off the ground, Very large, highly mobile west coast style yarders may be required. Another requirement may be portable tail holds for quick set up after moving. On large, flat tracts with an in-place road system, such a system may be economically feasible. Cable systems may also require intermediate supports to keep the logs off the ground. This concept, although untried and considered as too difficult may provide the only means of removing trees from many sites except with a helicopter.

Another new concept is that of a towed vehicle. If traction is provided by a drum at roadside, then specially designed, lightweight vehicles can carry more wood with less rutting. Since slip is zero, soil movement is reduced. Machine flotation can be increased when the power units are removed or reduced to only travel empty requirements. Such vehicles can be driven out and towed in, or towed both ways. They can be manually operated or remotely controlled.

Other methods may include more lift devices, such as balloons. When ground-based logging is impossible, the balloon can be used without regard to ground conditions. The concept al though feasible has only been economically marginal (Trewolla and McDermid 1969). Their costs have been prohibitive to date, but in the future their advantages may offset many costs. Helicopters have proved to be cost-effective in certain situations. Good production has been reported at short distances. More research is still needed to make this method a more cost-effective method for a wider range of conditions.

Road building is more disturbing to the site than harvesting. Also roads are expensive to build and maintain. Options include the use of specialty equipment that can haul on lower quality roads or transport the wood further without the use of roads. Another option is central tire inflation (CTI) systems that allow the use of low pressure tires on logging trucks. Trucks equipped with CTI can operate on low quality roads and may reduce road maintenance requirements.

Specialty matting and matting-handling equipment may help access the more difficult sites. Currently, matting is a cumbersome, unsophisticated method, but in the future it may become a primary method of wood removal as a result of research and trial use. The reason is that matting is a way of using low-quality roads for transport. Mats reduce the amount of earthwork and leave little residual disturbance.

Table 2. Summary of conventional harvesting systems for wet sites.

Function	Equipment options
Felling	Chainsaws, rubber-tired shears/feller-bunchers with wide or dual tires, tracked shear/feller-bunchers, and tracked, swing feller-bunchers.
Processing	Chainsaws and gate delimbing.
Extraction	Rubber-tired skidders include cable, grapple, cable-grapple, and clambunks; wide tires (34-44 inch) are used. Tracked skidders include flexible and rigid tracked designs.
	Shortwood and tree-length forwarders.
	Ground-based cable systems. Limited use of highlead cable yarding.
	Helicopters on a limited basis.

Summary

Harvesting timber on wet sites has always posed a problem to both logger and landowner. Over time, various methods have been used to economically harvest such sites. Typically, extraction methods have included specialized skidding machines. The basis for current operations is the use of rubber-tired skidders with wide tires. A summary of commonly used felling, processing, and extraction machines is presented in Table 2. The forest industry is aware that new, innovative methods must be developed which cause little site disturbance. Several new alternatives have been identified here.

Several machines have a particular application where they will excel above the others. We need to carefully consider our options and use our technology wisely to halt increased social regulation. More research is required to completely understand the options and to properly select and apply the technology as it is developed.

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SILVICULTURAL OPTIONS FOR WATERFOWL MANAGEMENT IN BOTTOMLAND HARDWOOD STANDS AND GREENTREE RESERVOIRS [1]

David J. Moorhead, John D. Hodges, and Kenneth J. Reinecke [2]

Abstract. Bottomland hardwood sites provide critical habitat for numerous wildlife species and are instrumental in providing wintering and nesting habitat for waterfowl. Manipulation of bottomland hardwood sites is possible through silvicultural activities to increase attractiveness and utilization by waterfowl. Historically, timber harvests that removed only the largest and most valuable trees in diameter limit harvests resulted in poorly stocked stands of increasingly shade tolerant, less valuable species for commercial use and waterfowl. Silvicultural practices that promote regeneration of desirable commercial species benefit waterfowl when properly applied. Silvicultural options which integrate forest and waterfowl management in natural bottomland hardwood stands and in intensively managed greentree reservoirs are reviewed along with impacts of sustained reservoir management on stand development, health, and reproduction.

Introduction

Bottomland hardwood sites provide critical habitat for numerous species of wildlife. These sites provide sources of mast and aquatic invertebrates as well as wintering and nesting habitat for waterfowl. Naturally flooded bottomland hardwood stands and greentree reservoirs (GTRs) are managed for waterfowl use. While waterfowl managers are concerned about the function of the entire forested wetland complex, considerable efforts are focused on the management of oak species which produce acorns utilized by waterfowl. Silvicultural practices that promote growth, quality, and regeneration of oak are invaluable to waterfowl managers. Oak species valued for their mast production and wood quality require openings in which regeneration can become established. Acorns will germinate under a closed canopy, but seedlings seldom persist for more than 3 to 5 years unless openings are created in the overstory canopy to release them (Johnson 1975). However, some managers may be reluctant to employ silvicultural harvesting methods to regenerate oak. This may be in part to past experiences or observations of improperly applied harvests which resulted in high-graded stands (Todd Holbrook, personal communication). Public perception regarding the aesthetics of harvesting operations on public management areas must also be considered.

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Value of Acorn Production

Acorns provide a valuable food source to waterfowl and are important components of overall food availability in wetland habitat complexes consisting of croplands, moist soil impoundments and bottomland forests (Reinecke et al., 1989). The importance of maintaining a productive oak component in waterfowl management areas is reflected by the varying feeding patterns of ducks in bottomland hardwood stands in relation to annual acorn production. As might be expected, during years of limited mast production, ducks may not feed in flooded bottomland hardwood stands, while during years of high acorn production, the crop is heavily utilized (Heitmeyer 1985, Combs 1987).

There are limited data available to quantify the production of acorns in bottomland hardwood stands and estimate their use by waterfowl. Timing and quantity of acorn and other mast crops is difficult to estimate. Environmental conditions as well as tree size, age, stand structure, and density influence production. Generally dominant trees with large, well-developed crowns prove to be the most consistent mast producers (McQuilkin and Musbach 1977, Francis 1983). Well stocked stands composed of large (> 27.9 cm dbh) trees produced 10 to 20 percent more sound acorns annually over a 14-year period than equally well stocked stands of smaller trees (< 25.4 cm dbh) in bottomland sites at Mingo Swamp in Missouri (McQuilkin and Musbach 1977).

Data from studies on Mingo Swamp can be used to relate the proportion of the oak component to acorn production and waterfowl use (Minckler and McDermott 1960, Minckler and Janes 1965, McQuilkin and Musbach 1977).

Table 1. Observed biomass of acorns in bottomlaud hardwood stands in Missouri at three levels of production (McQuilkin and Musbach 1977), and biomass predicted for other stands assuming acorn production is proportional to the percent basal area of red oaks among trees > 25 cm diameter at breast height (Reinecke et al., 1989).

Basal area of red oaks	Observed	Annual acorn production		
		Low	Average	High
(percent)		----- [kg(dry)/ha] [a] -----		
20	Predicted	1	18	51
40	Predicted	2	36	102
80	Observed	4	71	204

[a] Assumes dry weight of edible part of acorns = 0.5 x wet weight of whole acorns (K.J. Reinecke, unpublished data).

ACORN PRODUCTION

% BASAL AREA OF OAKS	Low	Average	High
20	–	–	?
40	–	?	+
80	–	+	+

Figure 1. Hypothetical responses of mallards to opportunities for feeding on acorns in flooded bottomland forests at three levels of acorn production and forest stand composition (Reinecke et al., 1989). (plus = positive response; minus = limited or no response, and; question mark = response unknown.)

Utilizing data from these studies, Table 1 was constructed to relate biomass production to the basal area of oaks greater than 25 cm in diameter. Assuming minimum acorn production necessary to attract feeding waterfowl is 50 kg (dry)/ha (Reinecke et al., 1989). The data suggest that production of sufficient levels of acorns to entice feeding occurs only at higher levels of oak stocking and during periods of high production. The hypothetical feeding response to levels of acorn production is illustrated in Figure 1. Consistent utilization by feeding mallards (Anas platyrhynchos) is only premed when the basal area component of mast producing oaks is 80 percent or greater. Managers must therefore be concerned about enhancing and maintaining the oak component in natural bottomland hardwood stands and GTRs.

Regeneration Systems

The perpetuation of desirable species within bottomland hardwood stands and GTRs is paramount to maintaining the productivity of these sites for waterfowl. Natural succession in bottomland hardwoods generally results in a shift to more shade tolerant species at the expense of more desirable oak species (Hodges and Switzer 1979, Lea 1988). Desirable oak seedlings are often present in the understory but seldom survive unless canopy openings are created to provide sufficient light to the forest floor. In bottomland hardwood stands in Missouri, Smith (1984) found that pin oak (Quercus palustris) seedlings growing under closed canopies survived less than 1 to 2 years. On sites in Mississippi, Nuttall oak (Q. nuttallii) seedlings were only l-m tall after 5 to 15 years of development in shade (Johnson 1975). Thus, openings created by harvesting serve to maintain quality bottomland hardwood habitat and facilitate use by waterfowl (Richard Kaminski, personal communication).

Harvesting can be utilized to influence the composition of the future stand. Adequacy of regeneration is dependent on existing species composition and selection of an appropriate harvesting method (Kennedy and Johnson 1984). Thinning can be used to favor desirable mast producers and satisfy aesthetics. Current stand conditions influence the selection of a silvicultural method.

The shelterwood harvesting system in which trees are removed in a series of partial cuts or thinnings gradually opens the overstory permitting increased light levels to the forest floor to stimulate seedling development. While this system has been recommended to regenerate shade intolerant species such as oak, results have often been disappointing (Sander 1979; Loftis 1983; Smith et al., 1983). Thinnings and weed control in the midstory and understory, and underplanting or enrichment plantings using bareroot or container-grown seedlings have promise in increasing the oak regeneration component in some stands with this system (Janzen and Hodges 1985; Nix et al., 1985; Hodges and Janzen 1987; Crunkilton et al., 1989).

The aim of the selection system is to create and maintain uneven-aged stands. Rarely has the selection system been properly applied on a commercial basis to achieve regeneration of oak. In the past, generally only the largest and most valuable trees were removed during harvest in many bottomland hardwood stands with no consideration to regeneration. Realistic evaluations of many diameter selection cuts indicate that they generally result in high-graded stands. Theoretically, mature trees are harvested and cuttings are made in all diameter classes to maintain a balanced size or age distribution of seedlings, saplings, pole, and sawtimber classes within the stand. Seldom is this achieved or even attempted in actual harvests.

A selection system is generally employed using the single-tree or group selection method. Mature trees are removed in the single-tree method with regeneration to develop in the opening created. This method is best suited to regeneration of shade-tolerant species and is not well suited for oak regeneration. Group selection openings less than 0.5 ha may be used to regenerate oak provided periodic improvement cuttings are employed to maintain growth of desirable species. The inefficiency and difficulty of regulating size classes limits the practical application of selection harvesting to regenerate oak.

Creation of an uneven-aged forest comprised of small, even-age patches established by clearcutting may be the most effective harvesting method to regenerate red oaks and to meet aesthetic requirements. Several silvicultural features are combined in this approach to regeneration. Small clearcuts involve elements of shelterwood, clearcut and coppice methods (Lea 1988). Managers should inventory sites to establish the presence of advanced regeneration in the form of seedlings along with the potential for coppice regeneration. Regeneration potential may be enhanced with a partial or shelterwood cut creating canopy openings required for seedling development. Complete removal of the overstory can occur when adequate regeneration potential is secured (Sander et al. 1976; Ashley 1979, Marquis and Bjorkhom 1982).

Openings of 0.5 ha and larger should be created to regenerate oaks. These openings, which may be as large as 4 ha are frequently referred to as "group selection" harvests. However, the application in this sense should not be confused with group selection cuts which are used in uneven-aged selection harvesting systems. Openings created for regeneration also serve as "blind" or "shooting" areas during waterfowl hunting seasons. Since the openings are relatively small and dispersed throughout the stand aesthetic problems may be minimized.

Perhaps the greatest drawback with natural regeneration is the lack of apparent early success of the method. After the final harvest, a "jungle" develops as herbaceous vegetation occupies the site and less desirable woody species dominate. Bowling and Kellison (1983) found that American hornbeam (*Carpinus carolinia*) initially dominated a clearcut site, but became suppressed as the stand developed. Release of desired seedlings by mechanical and/or selective single stem treatments with appropriate herbicides may be justified to encourage development of desirable seedlings and saplings.

Greentree Reservoir Management

Bottomland hardwood forests containing desirable mast producing species such as pin oak, cherrybark oak (*Q. falcata* var. *pagodaefolia*), water oak (*Q. nigra*), willow oak (*Q. phellos*), Nuttall oak, Shumard oak (*Q. shumardii*), and swamp chestnut oak (*Q. michauxii*) are frequently impounded to provide resting, feeding, and roosting habitat for wintering waterfowl. These GTRs are flooded during the dormant season using various systems of levees and other water control structures to maintain shallow water levels of 15 to 45 cm permitting use by dabbling ducks such as mallards, and wood ducks (*Aix sponsa*) . To avoid stand damage, water is drawn down in early spring before tree growth resumes (Mitchell and Newling 1986). The control of flooding in GTRs, provided a water source is available, allows for more consistent use of the resource by waterfowl. Flooding in natural stands is highly variable and often limits utilization by waterfowl. In bottomland stands along the White River National Wildlife Refuge in Arkansas, favorable water depths that permit ted feeding by mallard ducks occurred only during 58 percent of the winters (31 of 53) from 1932-85 (Reinecke et al., 1989).

Positive short-term tree and stand growth responses to GTR management have been attributed to increased soil moisture available during summer months resulting from dormant season impoundment (Broadfoot 1958). Radial growth increased 50 percent in a GTR that had undergone annual flooding for 4 years (Broadfoot 1967). However, studies over longer periods have indicated that annual flooding in a GTR reduced growth. Schlaegel (1984) found cubic-foot volume growth of Nuttall oak to be significantly reduced in a GTR that had been annually flooded for 17 years. Tree vigor was also declining resulting in greater mortality in the GTR compared with the nonflooded control stand. Growth in a pin oak dominated GTR was found to be reduced by annual flooding over a 20-year period, but GTR management did not appear to pose a significant threat to stand health (Rogers and Sander 1989). Although Rogers and Sander (1989) did not specifically account for mortality within flooded and nonflooded stands, Smith (1984) observed that mortality was higher in the GTRs. He attributed the overall reduction in basal area growth in the GTRs to increased mortality and reduced growth of individual trees.

Smith (1984) also found basal swelling damage in pin oak, cherrybark oak and southern red oak (*Q. falcata*) in a Missouri GTR. The damage was characterized by swelling of the stem at or above the mean water mark accompanied by bark fissuring and cracks. Damage was not observed in the white oak group (subgroup *Leucobalanus*) or other tree genera.

Dormant season and short-term flooding during the growing season may have little detrimental initial effect on mature, flood tolerant species. Black (1984) examined the water relations of mature (40 to 45 years old) pin oak trees exposed to dormant season, short-term flooding during the growing season, and continuous flooding. Repeated flooding for more than 20 years during the dormant season did not affect phenology or physiology of mature trees. Pin oaks maintained uniformly high leaf conductance throughout the growing season on both control and dormant season flooded plots with no hydroactive stomata1 closure at midday. In contrast, upland oak species conserve water by reduction in midday stomata1 conductance (hydroactive stomata1 closure) in response to seasonal limitations in soil moisture (Thompson and Hinckley 1977; Hinckley et al., 1978). Apparently the root systems of pin oak on these sites were able to maintain contact with the normally shallow water table throughout the growing season (Fredrickson 1979).

Short-term flooding (30 days) late in the growing season (September) resulted in midday stomata1 closure within 5 to 6 days after flooding. Stomata1 closure was not attributable to the development of plant water deficits as leaf water potential (xylem pressure potential) remained high. Measurements of osmotic and matric potentials indicated that no changes occurred in response to short-term flooding that may have influenced soil-plant resistance to water uptake (Regehr et al., 1975). Midday stomata1 closure proved transient and stomata1 function recovered within 14 days after flooding. Onset of autumn coloration and leaf senescence in trees on flooded plots began 2 weeks earlier than in control trees.

When plots were continuously flooded for 2 years, few changes in phenology and water relations occurred in the mature trees (Black 1984). Flowering, leaf initiation and development proceeded normally in both flooded and control plots. However, development of autumn coloration, leaf senescence and abscission occurred 2 weeks earlier on trees in the flooded plots. No significant differences in diurnal parameters of xylem pressure potential or stomata1 conductance were detected among trees in flooded and control plots during the first year of continuous flooding.

During the second year of continuous flooding, water relations parameters and leaf initiation and expansion were unchanged. However, flowering frequency was reduced on trees in continuously flooded plots. Acorns which had initiated development the previous year, aborted by mid-June. Leaves of the continuously flooded trees became chlorotic in August and abscised 2 weeks earlier than leaves of control trees. Broadfoot (1958) observed similar responses of cherrybark oak and willow oak in the second season of continuous flooding.

Mast Production

Of prime importance to wintering waterfowl in their use of GTRs is the availability and abundance of food items. Wood ducks and mallards feed on mast produced by various tree species and on aquatic invertebrates. The small seed oaks are preferred although seeds of baldcypress, maple, ash, water hickory (Carya aquatica), tupelo (Nyssa sp.), sweetgum (Liquidambar styraciflua), American hornbeam, hawthorne (Cratagus sp.), wild grape (Vitus sp.) and other species are utilized, particularly when acorn production is limited (Smith 1985, Mitchell and Newling 1986).

Acorn production is typically cyclic with peak production occurring at 4- to (i-year intervals. Over a 14-year study period (1956 to 1969), peak production occurred in 1957, 1961, and 1966 (McQuilkin and Musbach 1977). Production is related to both temporal and spatial factors affecting fertilization, development and maturation (Downs and McQuilkin 1944, Gysel 1956). Minckler and McDermott (1960), Minckler and Janes (1965) and McQuilkin and Musbach (1977) examined acorn production in a GTR in Missouri and concluded that dormant season impoundment did not adversely affect the number of sound acorns ultimately available in any given year. However, total acorn production was significantly greater in naturally flooded control plots compared with the GTR plots (McQuilkin and Musbach 1977). Similar reduction in acorn production by Nuttall oak in GTRs was documented by Francis (1983). However, the percentage of acorns infested by weevils (Curculio spp.) was found to be twice as great on naturally flooded plots as in GTR plots (McQuilkin and Musbach 1977). This resulted in an approximate equal number of sound acorns available in both the control and GTR plots. Pupae overwintering in the soil were apparently killed by dormant season flooding in the GTR plots reducing insect pressure (Minckler and Janes 1965, McQuilkin and Mushbach 1977).

Acorn production suffers, when water tolerant species are flooded for several years throughout the growing season, from both reduction in flowering (Black 1984) and death of trees (Broadfoot 1958, Francis 1983). Failure to completely drain dormant season flood waters may lead to pockets of reduced mast production and tree mortality if soils remain saturated during the growing season (Fredrickson 1980).

Regeneration

Regeneration of desirable species is critical in GTR management. Seeds which mature and shed in the fall must withstand submergence in GTRs for up to 5 or 6 months before germination. Most oak species can remain viable in GTR conditions with little reduction in germinative capacity; in fact, cool temperatures and moist conditions enhance stratification required by species in the subgenus Erythrobalanus (red oak group) to overcome internal dormancy (Korstain 1927, Briscoe 1961, McDermott and Minckler 1961, Johnson 1975).

Seeds of other tree species common in bottomland hardwood systems show the ability to successfully germinate after stratification in standing water (DuBarry 1963). Shifts in species composition may result when desirable seed producing trees die or are harvested. A gradual shift from pin oak to less desirable and more flood tolerant overcup oak (Q. lyrata) has been observed in a Missouri GTR under management for 20 years (Fredrickson 1979, Smith 1984). Smith (1984) also found that oak seedlings developing under the closed canopy of mature trees in a GTR rarely survived for more than 1 year after germination. As the number of oak seedlings in the understory declined, red maple (A. rubrum) and American elm (Ulmus americana), more shade and flood tolerant species, increased in frequency.

Seedling response to flooding varies among species with respect to timing, depth, and duration of flooding (Hosner 1958, 1960; Louckes and Keen 1973; Krinard and Johnson 1981). Common plant responses to flooding are rapid stomata1 closure, reduction in photosynthesis, alteration in plant hormonal balances , and increased resistance to absorption of water and nutrients (Kozlowski 1982, Kozlowski and Pallardy 1984).

When flooding is prolonged seedlings unable to adapt to, or recover from, flooding will die. Cherrybark oak, valuable for timber and wildlife use, is an important component of many bottomland forests. It is found along floodplains on the better drained soils of ridges and terraces that are subject to periodic natural flooding and is a common species in many GTRs. When subjected to flooding, cherrybark oak seedlings exhibited rapid stomata1 closure without development of internal plant water deficit, and rapid reduction in net photosynthesis (Pezeshki and Chambers 1985). Recovery of stomata1 function after termination of flooding was slow and incomplete, indicating loss of stomata1 control. Seedlings of flood tolerant species such as green ash (Fraxinus pennsylvanica) have shown ability to adapt to flooding by reopening stomata and rapidly recovering normal stomatal function after termination of flooding (Kozlowski and Pallardy 1979). Green ash, water hickory, and overcup oak leaf out up to a month later than other less flood tolerant species, thereby avoiding growth and metabolic stress that would accompany spring floods (Broadfoot and Williston 1973).

Recharge of soil moisture in GTRs has been seen as beneficial to overall growth of mature trees, particularly during summer droughts. However, saturated soil conditions during early spring when drawdown of water in a GTR is delayed or incomplete can have detrimental effects on less flood tolerant species such as cherrybark oak which may be unable to recover from flooding damage even as the site dries out (Pezeshki and Chambers 1985). Smith (1984) noted that while regeneration of pin oak from seed was abundant in openings within mature stands when seed bed conditions were favorable, little regeneration occurred in mature stands and few seedlings survived for more than 1 or 2 years. Johnson (1975) found that Nut tall oak seedlings were not able to remain viable beneath a closed canopy because of reduced light levels. Photosynthesis in l- and 2-year-old pin oak seedlings growing in naturally flooded and continuously flooded plots was found to be primarily limited by low light levels in the unders tory (Moorhead, unpublished data). Pin oak seedlings in the flooded plots maintained higher leaf water potentials than seedlings in the nonflooded control plots, yet stomata1 conductance was not significantly different between plots. Gross photosynthesis by flooded seedlings was 48 percent less than nonflooded seedlings suggesting probable nonstomatal photosynthetic limitation. Long-term reduction in photosynthetic capacity is related to a complex of factors such as reduced leaf chlorophyll content, early onset of leaf senescence and abscission, reduced leaf area, and altered hormonal relations, particularly ABA, cytokinin, and ethylene (Bradford 1982, Kozlowski 1982).

Suggested GTR Management Guidelines

To provide wintering habitat for migrating waterfowl, reservoir pools should be filled during early fall. Inundation may begin in mid-September in northern GTRs and continue until mid- to late October in southern states. Water drawdown should begin by mid-February. Low areas within the GTR may trap water which may eventually kill less flood tolerant species. Unless drainage is facilitated in low areas, vegetation will likely revert to more flood tolerant and less desirable vegetation.

Control of timber harvesting and water management are the most useful tools in maintaining the productivity of GTRs. Clearcut harvests in small blocks or patches to create openings in the stand will promote regeneration and can serve as shooting areas. Thinnings in the midstory and understory of mature stands can increase the number of oak seedlings available as advanced regeneration sources (Janzen and Hodges 1985). Lacking suitable regeneration, underplantings or enrichment plantings of desirable species can increase the advanced regeneration component prior to harvest (Nix et al., 1985).

Annual dormant season flooding restricts regeneration from seed and reduces the viability of seedlings that are established. Following good seed production years, dormant season flooding should be withheld until seedlings become well established in the understory (2 to 3 years). Thinnings and openings in the overstory are required to provide sufficient light for seedling development. Seedlings may require release from rapidly developing competition using spot treatments of herbicides.

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OLD-GROWTH FOREST MANAGEMENT FOR MULTIPLE USE[1]

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Abstract. This paper is a discussion of management practices developed to provide the visiting public with attractive, large-diameter stands of hardwoods on Land Between The Lakes (LBL) . The background history of the LBL area, stand and site selection, and multiresource objectives of stands (aesthetics, habitat diversity, research, recreation and environmental education, and timber) are discussed.

Introduction

The old-growth forest management program at Land Between The Lakes (LBL) might best be described as a still-evolving effort to maintain or restore old growth forest conditions to meet many public and management objectives. Land Between The Lakes itself was established by the Tennessee Valley Authority (TVA) in 1963 to be a national demonstration in outdoor recreation, environmental education, and natural resource management . The long-term goal of LBL forest management has been to provide a distribution of forest age classes that will support diverse native wildlife populations, while maintaining an aesthetic setting for outdoor recreation, and improving the quality of the timber resource. Other issues that emerged over the years have been incorporated into goals for resource management as well, particularly the enhancement of stands of large trees in prominent locations for public viewing. In 1985, new goals included designation and management of 10 percent of the forest for old-growth development. In 1990, TVA began revising its resource management strategy for LBL once again, in concert with an Environmental Impact Statement to evaluate the effectiveness of six management alternatives in suiting today's public needs.

Area Description

Land Between The Lakes is located in west Kentucky and Tennessee between the Tennessee and Cumberland Rivers, within the Western Mesophytic Forest Region defined by Braun (1950). This is a transitional region between the mixed mesophytic forests of the Appalachians and Cumberlands to the east, and the oak-hickory forests to the west and north. Today, of the 63,132 ha (156,000 ac) of forested land, approximately 87 percent is classified as oak-hickory, five percent is in blackjack oak-post oak, and the remainder is composed almost equally of pine and bottomland hardwood types. White oak (Quercus alba), black oak (Q. velutina) , and combined hickories (Carya spp.) compose

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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37, 11, and 11 percent, respectively, of total hardwood growing stock (Groton et al., 1988). Cores taken in 1987 from dominant and codominant trees indicate ·that about 45 percent of trees exceeding 29.2 cm (11.5 inches) dbh, exceed 100 years of age (Groton personal communication, 1988).

The area experienced man-caused disturbance beginning with native American hunters who set fires to flush out game. White settlers began moving into the area by 1780. They established farms along the Tennessee and Cumberland Rivers, and cleared the bottomland forests. In the 1830s, extensive cutting and burning of upland forests accompanied the burgeoning iron industry. About 202 ha (500 ac) of forest were cleared to provide charcoal for each furnace for its 8- to lo-month blast cycle, and six furnaces operated within the area. After the iron industry declined, most of the remaining timberland was cut over for railroad ties, or remained in farms where routine woods burning and livestock grazing continued until the late 1930s (Henry 1975).

Approach to Management

How would one begin to manage for old-growth in a highly disturbed second- or third-growth forest? During routine forest inventories, LBL foresters came upon a few stands of large trees that seemed relatively undisturbed. Beginning in the 1960s, these stands were aside as Ecology Study Areas reserved for long-term ecological research. By 1980, 29 such stands had been located, each averaging about 16 ha (40 ac) in size.

Also, TVA's area-based management has allowed a yearly maximum of 202 ha (500 ac) of even age regeneration using small clearcuts or shelterwood, with the total harvest removing about one-third of the annual growth. Excluding the Ecology Study Areas, maintained open lands, and facility grounds leaves 61,943 ha (153,000 ac) on nearly a 300-year rotation. As with many other public forests that are growing more timber than they are harvesting, some of our staff felt that a 300-year rotation was itself sufficient to insure maintenance of old-growth forest. With LBL's diversity of objectives, though, substantive criteria were needed to select the best candidate stands rather than depending on the system to generate adequate old-growth by default. As with most multiple use programs, each stand designated for old growth management in LBL will satisfy several objectives, but perhaps not the entire range of old growth values. The criteria we have applied are based on the values we associate with old-growth forest: aesthetics, habitat diversity, research, recreation and environmental education, and timber.

One of the most important reasons people visit LBL is to enjoy the natural scenery, and most of them do so while driving rather than walking (Cordell et al., 1987). We try to ensure that they will experience "old growth or old-looking" forests by managing selected stands to grow large-diameter, large-crowned trees visible from facilities, roads, and shoreline. This is accomplished through single tree selection or thinning from below to create and maintain "park-like" conditions. D.M. Smith defined silviculture as, " the art of producing and tending a forest (Smith 1962) ." Artful silviculture, applied in stands having good site quality, diverse overstory species composition, and large, healthy trees can effectively maintain an attractive stand over a long period.

Habitat diversity is probably the single most important function served by old-growth stands. Research has identified specific components present in old-growth forests that younger forests (or forests intensively managed) normally have not had time to develop (Meyer 1986; Pyle 1988; Thomas et al., 1988). These components include numerous standing snags, large numbers of large diameter logs, and diversity in vertical stand structure resulting from uneven light penetration. However, it is not uncommon to find these elements in LBL stands dominated by 70- to 90-year-old trees resulting from the oak decline syndrome during the early 1980s. Like many other land managers, we would like to know if old-growth habitat can be provided by relatively young, though decadent, stands. Few such stands have been designated in LBL for old-growth management because their contribution would seem to be short-lived.

The issue of stand size seems best addressed in relation to habitat values. How big is big enough? Can small, isolated "gems" of potential old-growth be retained as they occur throughout the forest, or should large blocks presently comprised of diverse ages be withdrawn from management to encourage their development toward old growth? In LBL, stands offering unique opportunities for old-growth development have been retained regardless of size, as with the 29 small Ecology Study Areas. But some ecologists contend that small stands have too much edge proportionally to provide the deep forest condition required by interior woodland species. At present, LBL's forest canopy is largely unbroken, with only about 6 percent in young growth and 9 percent in maintained open fields. Is the edge between a potential old-growth stand and another second-growth sawtimber stand a significant hindrance to interior species? We are taking steps to retain some larger blocks, although information is incomplete regarding indigenous species that require this type habitat. Four large watersheds (totaling 2,080 ha; 5,200 ac) designated as core areas under the International Biosphere Reserve program are being withdrawn from active management, and will eventually grow old. A study now underway by the Department of Geology of Southern Illinois University should provide useful information about the size of buffer areas needed around the small study areas and the larger watersheds.

The issue of how much old growth also seems most relevant to habitat. Land Between the Lakes' current resource management plan calls for management of 10 percent of the LBL forest as old growth, based on recommendations for habitat management in similar oak forest in Missouri (Meyer 1986). By 1987, 10.4 percent of the LBL forest had been designated for some type of old-growth management. As TVA now begins to consider several resource management alternatives for LBL, 10 to 100 percent of the area will be evaluated for management as old-growth forest.

Basic scientific values are served by retention and/or restoration of some old-growth forest. Many questions about old growth will only be answered through extremely long-term ecological studies. How old is old-growth in eastern hardwoods? Is a stand old-growth as soon as it exceeds financial maturity or biological maturity? Is a stand considered old-growth when those species (flora and fauna} requiring old-growth for survival appear? Do we know those species? If a stand growing on a poor site begins to fall apart sooner than expected, should that site be managed indefinitely for old growth? With the entire LBL forest on a long rotation, need we be concerned with providing replacement stands for old growth? Even if we are unable to answer these questions now, we must consider which types of resource management will allow future scientists to answer them. Baseline inventory data have been collected from the Ecology Study Areas by Murray State University which may eventually provide answers regarding edge effect. Requests from researchers for large set-aside acreages will be accommodated by the core watersheds for the Biosphere Reserve. We would like to see studies begin immediately in these areas, especially to document current conditions in the most highly disturbed portions of the watersheds. Another consideration is the inclusion of stands representing all indigenous forest cover types. Over the next 2 years, the LBL forest stand data base will be linked to a geographic information system making confirmation of this objective possible.

The value of old forests for public recreation is apparently very high. Land Between the Lakes' dual mission of recreation and environmental education is served by providing access into old-growth stands and opportunities to observe differences between stands of other ages. Such stands as the Bear Creek Natural Area allow hikers along the Fort Henry Trails to view the contrast between naturally developing old growth and the planned interspersion of fields with young, intermediate, and mature forest. In other areas, examples of thinned stands of large trees have been educational for visitors who see alternative cutting practices for their own woods.

Growing large trees for profit is not a goal of LBL old-growth management. However, over time, even low thinnings or single tree selection will yield high value logs. Some of the managed stands will be located on good auality mesic sites, producing white ash (Fraxinus americana). American beech (Fagus grandifolia), sugar maple (Acer saccharum), and yellow-poplar (Liriodendron tulipifera), in addition to northern red (Q. rubra) and white oaks. Continued protection from fire and infreauent light harvests should allow healthy stands to be carried past economic or biological maturity.

Problems

As mentioned earlier, the LBL old-growth program is still evolving. Many LBL staff have expressed concerns about objectives, about selection, and especially about silvicultural treatments planned for some stands. Even disagreement over terminology is a problem. Some staff reject use of the term "old-growth management" for any stands not under complete preservation status. The foresters, however, feel that many objectives call for many management approaches, and tend to agree with the statement made by Neil Sampson this spring before House subcommittees: "We reject the notion that the only two choices are total preservation or total conversion to second-growth forests (Gray 1990)."

The foresters debate inclusion of too much low quality timber on xeric sites and too much high quality timber on mesic sites. The wildlife biologists are somewhat divided over the sizes of old-growth areas: one prefers dispersed small stands and another tends toward the large block premise. Locations for various types of forest management are of concern to everyone. We have conducted low thinnings for old growth within campgrounds after closely coordinating the harvesting operations with recreational uses. Even though the results have had positive long-term results, yielding attractive stands of vigorous trees, some people feel the short-term visual disturbance caused by thinning is too high a price. Another consideration is the role of fire in designated old-growth management stands. Given the wide dispersal of stands, the proximity of some to visitor use areas, and the historic role of fire in the development of the oak forest, our managers are faced with many conflicting views regarding both the use of fire to manage stands and the suppression of wildfire in unmanaged stands.

Conclusions

Resolution of these issues may change some of our approaches to old-growth management, as could findings and functional recommendations from other managers and researchers. Two recent conferences on old growth have both confirmed some of our approaches and challenged us to seek even more answers. The 1989 meeting of the Natural Areas Association held in Knoxville, Tennessee, suggested that managers begin by defining distinguishing features of old-growth forest and considering the appropriateness of management systems for old growth. At LBL, we have determined distinguishing features to be:

- Little evidence of disturbance by man
- Presence of big trees. In west Kentucky and Tennessee, upland oaks averaging larger than 45 cm dbh may be considered big trees
- Abundance of dead standing snags and fallen logs, also of large diameter
- Mesic sites
- Xeric sites
- Diverse overstory species composition
- Diverse understory species composition
- Old stands
- Decadent stands
- “Pretty” stands

At LBL, old-growth management hinges on objectives, with a diversity of objectives requiring a diversity of approaches. We believe LBL's approaches meet some of the objectives common to other public lands. Silvicultural treatments can be used to enhance the long-term aesthetic appeal of a stand. Classical low thinning accelerates the natural thinning process by selecting for harvest those trees most likely to die from overhead shading for the next 30 years or so. There are short-term trade-offs with this approach, but careful planning and implementation of silvicultural or logging operations can minimize visual impacts. Stand manipulations for habitat values should be undertaken with caution. Certain wildlife species such as cavity nesters and woodpeckers can benefit from silvicultural treatments that create standing snags, large fallen logs, and diverse vertical structure. Large diameter cull trees can be girdled, injected, or felled, singly or in clusters. The resulting gaps in the forest canopy will stimulate development of a multi-storied effect. Where these habitat components are needed and are lacking, silvicultural practices can indeed provide them. The preservation approach alone involves simply waiting for decades. Clearly, the idea of manipulating a stand toward old growth is controversial among managers, ecologists, and the public. Both approaches deserve to be tested for research values. Since disturbance is the rule rather than the exception in eastern forests, the old growth of tomorrow will necessarily derive from disturbed forest. Rather than exclude managed areas from old-growth research, we need to begin long-term studies in disturbed forest in order to understand the effects of management.

At a recent Forest Service conference in Arkansas, Chris Maser of the Environmental Protection Agency recommended that anyone delving into old-growth forest management answer the following questions:

Why old-growth--just what is the objective?
What is old-growth?
Where should it be located?
How much old-growth is needed?
When does a stand qualify as old-growth?
How long does a site remain old-growth?

At LBL, we have attempted to answer these questions through both active and passive approaches to management. Undisturbed old-growth forests barely exist in the Eastern United States. This should stimulate efforts to restore old-growth conditions within carefully selected disturbed forests. Aldo Leopold cautioned that we should at least save the cogs and wheels as we engage in “intelligent tinkering” with our natural resources. Natural resource managers should work toward restoration of old growth, not only to provide for benefits we can appreciate in the short-term but especially so that future generations can realize the ultimate value of these forests.

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VARIATION IN SLASH PINE CONE SPECIFIC GRAVITY AND THE SIGNIFICANCE TO CONE HARVESTING [1]

Stephen W. Fraedrich and Frank J. Spirek [2]

Abstract. Premature cone harvesting can reduce the quality of pine seeds. Specific gravity is an accepted indicator of cone maturity. In experiments which were conducted in a slash pine seed orchard, cone specific gravity varied within the crowns of individual trees, among trees of the same family, and particularly among families. Cones located on the north sides of trees had lower specific gravity values than cones on the south sides. Cone specific gravity also differed among trees of the same family, but differences within crowns and between trees of the same family were small relative to differences between families. Cones were ready for harvest as much as 1 month earlier in some families as in others. Cone harvest times should be evaluated with respect to cone maturation of families or clones in those orchards which have problems with seedlot quality.

Introduction

Establishment and operation of southern pine seed orchards are too costly to permit preventable losses in the yield and quality of genetically improved seeds. In his study of maturation of ponderosa pine (*Pinus ponderosa* Laws.) seeds, Maki (1940) emphasized that "germinative capacity of seed is so vitally affected by time of cone harvest that extreme care is warranted in ascertaining the proper time for undertaking actual cone gathering." Specific gravity has been used as a reliable indicator of cone maturity of many conifers (Edwards 1980).

Cone specific gravity decreases due to moisture loss as cones ripen (Barnett 1978), and as specific gravity decreases the proportion of viable seeds generally increases. For instance, germination of red pine (*Pinus resinosa* Ait.) seeds gradually increased, from 0 to 83 percent, as the cone specific gravity at harvest decreased, from 1.0 to 0.82 (Rudolf 1940). In addition to the effect on total germination, cone harvest time also can affect germination rate, storability, and disease incidence in seeds (Eliason and Hill 1954; Allen 1958; Fraedrich et al., 1989). Barnett (1976) states that optimum seed yields and germination with slash pine (*Pinus elliottii* Engelm. var. *elliottii*) are achieved only when mature cones are harvested. Guidelines established by Wakeley (1954) indicate that slash pine cones are mature when their specific gravity decreases to less than 0.89.

Differences in cone maturation rates among trees and within the

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crowns of individual trees could pose difficulties in determining the optimal time for cone collection. Maki (1940) and Rietveld (1978) reported that the specific gravity of ponderosa pine cones did not vary significantly within the crowns of a single tree, but did vary widely among trees. The dates of cone maturation for individual trees of other conifers also vary significantly (Fowells 1949, Cram and Worden 1957, Cram and Lindquist 1979). Based on discussions with seed orchard managers at several southeastern locations, cones from various slash pine clones or families are believed to ripen at different rates. For economic reasons, however, many managers collect all cones at the same time and the seeds for all families or clones subsequently are bulked. Differences in cone maturation within trees, within families and clones, and among families and clones have not been adequately assessed and documented for slash pine. In this paper such variations are evaluated.

Materials And Methods

Three experiments were conducted in a slash pine seed orchard near White Springs, Florida (Hamilton Co.). In all experiments, cone specific gravity was determined by the technique of Barnett (1979). The first experiment was conducted on 7 September 1989. The crowns of two trees from each of four families were divided into four sections, i.e., the upper and lower halves of the north and south sides. Three cones were selected in each section for specific gravity determinations.

A second experiment was initiated on 15 September 1989, and this experiment was essentially an expansion of the first. Three ramets for each of six clones (18 total trees) were used in this experiment. Three cones were collected from each of the four crown sections of each tree. Two clones, 08-02 and 08-04, had a common female parent, and two other clones, 62-01 and 62-02, also had a common female parent. The experiment was established in this manner to evaluate the variation among clones which would be considered members of the same family.

In the third experiment the relative maturation rates among slash pine families was assessed by selecting four trees from each of three families (12 total trees) and removing sample cones at weekly intervals from 4 September through 4 October 1990. The families were selected to represent trees which were considered to have early (family 037), intermediate (family 008), and late (family 007) maturing cones. At each sampling time, five cones were obtained for specific gravity determinations from the southeast portions of the trees.

Experiments 1 and 2 were analyzed as split-plot designs in which families or clones were whole unit factors and crown section was a subunit factor. Cone specific gravity was the response variable in all experiments. Contrasts were used to determine differences between north and south sides, and upper and lower crown portions.

Results And Discussion

In experiment 1, no differences were observed in cone specific gravity between families (Table 1). A relatively small but highly significant difference in specific gravity was observed between cones obtained from the north and south sides of trees ($P < 0.01$). Cones obtained from the south sides of trees had higher specific gravity values than those from the north sides (Fig. 1). The family x crown location interaction was not significant.

Table 1. Analysis of variance for split-plot design in experiment 1: evaluation of differences in cone specific gravity with respect to slash pine family and crown location.[1]

Source	Df	Mean square	F value	Prob. > F
Families (F)	3	0.04593	2.94	0.1623
Trees/F	4	0.01562	6.02	0.0067
Locations (L)	3	0.02083	7.81	0.0037
"North vs south"	1	0.06015	23.21	0.0004
"Upper vs lower"	1	0.00051	0.20	0.6656
F * L	9	0.00378	1.48	0.2659
Trees * L/F	12	0.00259	1.97	0.0416
Sampling error	64	0.00131		

[1] Family and location were fixed factors. "Trees within families" (Trees/F) was the error term for the whole unit analysis. "Trees * location within families" (Trees * L/F) was the error term for the subunit analysis and for the test of differences among trees within families.

In experiment 2, no differences were detected in cone specific gravity among clones (Table 2). Differences were not anticipated since clones selected were early to intermediate in cone maturation based on results of other studies during preceding years (Fraedrich, unpublished information). A difference in cone specific gravity between clones 08-04 and 08-02 was statistically nondetectable. However, in other studies during the last several years cones of clone 08-04 consistently had lower specific gravity values than cones of clone 08-02 at any given time (Fraedrich, unpublished information). Therefore, an experiment with increased sampling may facilitate detection of the contribution of the male parent in determining cone maturation rates. Differences in cone specific gravity between ramets of certain clones were significant ($P < 0.001$), but these differences were small for most clones (Fig. 2). The observed differences in specific gravity between certain ramets of a clone were probably due to subtle environmental influences between tree locations, e.g., shading by neighboring trees and site variation. In experiment 2, as in experiment 1, cones from the south sides of trees had significantly ($P < 0.001$) higher cone specific gravity values than cones from the north sides of trees (Fig. 3). In addition, the mean specific gravity of cones was slightly greater in upper than in lower crowns ($P < 0.05$). This difference was minor and inconsistent among trees. Evidence of a clone X crown location interaction was absent .

Table 2. Analysis of variance for split plot design in experiment 2: evaluation of differences in cone specific gravity with respect to slash pine clone and crown location.[1]

Source	Df	Mean square	F value	Prob. > F
Clones (C)	5	0.04177	1.65	0.2215
Trees/C	12	0.02535	13.20	0.0001
Locations (L)	3	0.02117	11.03	0.0001
"North vs south"	1	0.05178	26.90	0.0001
"Upper vs lower"	1	0.01136	5.90	0.0202
C * L	15	0.00248	1.29	0.2586
Trees * L/C	36	0.00192	1.57	0.0329
Sampling error	143	0.00122		

[1] Clone and location were fixed factors. "Trees within clones" (Trees/C) was the error term for the whole unit analysis. "Trees * location within clones" (Trees * L/C) was the error term for the sub-unit analysis and for the test of differences among trees within clones.

Differences in cone specific gravity within the crowns of trees may have implications in cone sampling to determine readiness of cone crops for collection. If samples to determine cone maturation are taken from one portion of a tree crown, results may be unreliable. Thus, when establishing appropriate collection times, cone samples should be collected throughout the crowns of individual trees as well as from more than one tree of a clone or family.

The cone specific gravity values of three slash pine families during the weeks immediately prior to cone opening are presented in Figure 4. Based on specific gravity measurements and on the guidelines proposed by Wakeley (1954), cones of family 037 were ready for collection on the first sampling date (4 September). The mean cone specific gravity for this family was 0.78 at this time, and most values ranged from 0.74 to 0.81. Although the mean cone specific gravity of family 008 was 0.85 on 4 September , some cones had specific gravity values as great as 0.92. Collection of family 008 should have been delayed until 12 September when mean cone

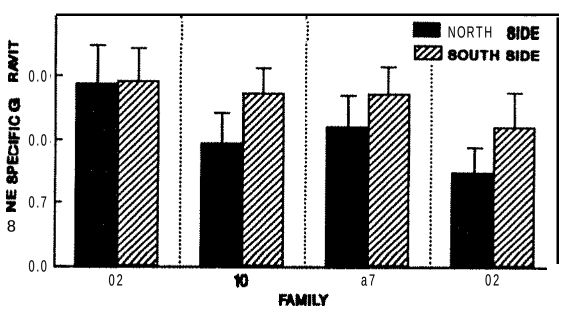

Figure 1. Mean cone specific gravity with respect to crown position for each family in experiment 1. Lines above vertical bars represent one standard deviation.

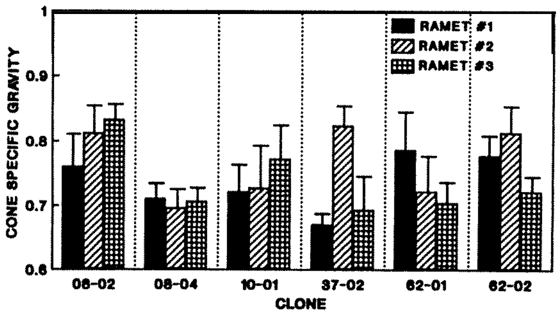

Figure 2. Mean cone specific gravity with respect to ramets of each clone in experiment 2. Lines above vertical bars represent one s tan– dard deviation.

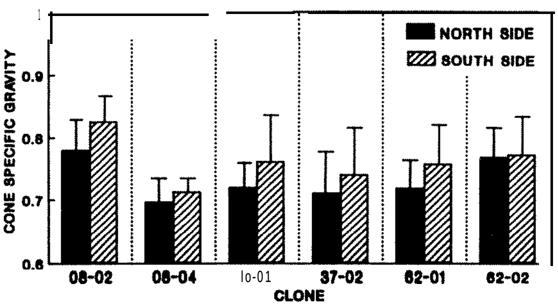

Figure 3. Mean cone specific gravity with respect to crown position for each clone in experiment 2. Lines above vertical bars represent one standard deviation.

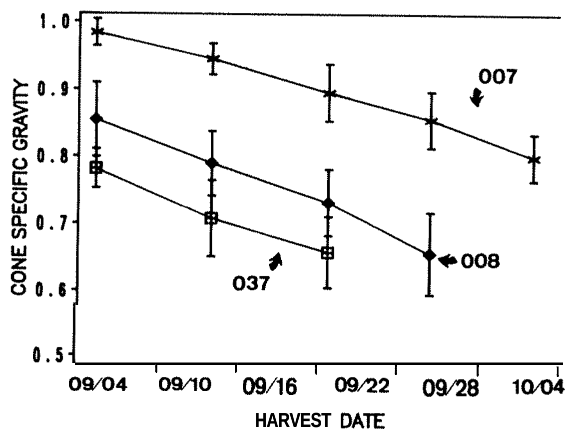

Figure 4. Mean cone specific gravity with respect to collection date for three slash pine families in experiment 3. Lines above and below means represent one standard deviation.

specific gravity was 0.79 and individual values ranged from 0.70 to 0.85. Cones of family 007 were not ready for collection until early October. On 4 September, the mean cone specific gravity of this family was 0.99 and values ranged from 0.96 to 1.01. Mean cone specific gravity had decreased to approximately 0.85 on 27 September , but values still ranged to 0.92. Cone collection for this family should have begun in early October to maximize seed yield and quality. On October 4, the mean cone specific gravity of family 007 was 0.80 (range, 0.75 to 0.88).

Results of experiment 3 illustrate the diversity in cone maturation rates which can exist in a slash pine seed orchard and the potential difficulty that orchard managers can experience in establishing appropriate collection times. Use of a cone specific gravity threshold of 0.89 to initiate harvest of an entire orchard has obvious limitations. Based on results from experiment 3, collect ion of cones of family 007 would not have been advisable until well after cones of others families had opened. Barnett (1976) reported that slash pine cones could be harvested when their specific gravity was as great as 0.95, however, seed viability for such cones was lower than for cones with lower specific gravity values at harvest. In other species of conifers, premature cone collections also have caused poor seed storability and reductions in rate of seed germination (Eliason and Hill 1954, Allen, 1958). More recently, slash pine seeds had a greater incidence of disease when cones were harvested at specific gravity values above 0.85 (Fraedrich, et al., 1989). Seeds from cones of family 007 remained susceptible to disease for longer durations than seeds from other families. The lengthened period of disease susceptibility of family 007 is apparently linked to the slower maturation of these cones.

Cones of late-maturing families are typically collected at the same time as cones of early-maturing families. Orchard managers experiencing difficulties with slash pine seedlots should evaluate the time of collection with respect to the cone maturation time of families and clones in their orchard. The premature harvest of cones could be one factor involved in the production of low quality seedlots.

Conclusions

Cone maturation times can vary significantly among slash pine families. Based on specific gravity measurements, cone maturation for one family in this study lagged behind the earliest maturing family by approximately 1 month. Although differences in cone specific gravity were observed within the crowns of trees and between trees within families, these differences were small in comparison with the differences between certain families. Orchard managers experiencing difficulties with seedlot quality should evaluate maturation times of individual families or clones with respect to time of harvest.

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VOLUME PRODUCTION OF SIX CHERRYBARK OAK PROVENANCES IN THE WESTERN GULF REGION [1]

Thomas A. Greene, William J. Lowe, and Mike Stine [2]

Abstract. In 1980, two sets of cherrybark oak (Quercus falcata var. pagodaefolia Ell.) genetic tests were established in the Western Gulf region. The first set contained 30 open-pollinated families from six provenances in Texas, Arkansas, Louisiana, and Mississippi. The tests were established in Cass County, Texas, and St. Landry Parish, Louisiana. The second set of tests was established in Tyler County, Texas, and Warren County, Mississippi, and contained 26 families from the same provenances. After 10 growing seasons, height, dbh, and planted-tree volume were assessed for all test trees. Significant differences among provenances and families within provenance occurred in all tests for the measured traits. The north Louisiana provenance consistently outperformed all other sources, while the north Mississippi source always ranked last. This study indicates that seed from the north Louisiana source should be used for artificial regeneration programs in the four regions represented by the genetic tests. However, studies involving seed movement should be considered tentative until the tests on which they are based reach at least one-half rotation age.

Introduction

Cherrybark oak (Quercus falcata var. pagodaefolia Ell.) is an important component of southern hardwood forests. It ranges from eastern Texas north along the Mississippi River to southern Illinois and Indiana, and east to southeastern Virginia (Fowells 1965). Cherrybark oak has been the subject of substantial silvicultural investigation (see for example Clatterbuck and Hodges 1988, Guldin and Parks 1989). However, very little information about the genetics of the species has been published. Schoenike et al. (1982) reported on two 11-year-old southern red oak (Quercus falcata Michx.) provenance tests in South Carolina. Differences in growth and survival were found among provenances, but no geographic trends were identified in their data. Dicke and Toliver (1987) compared growth in two halves of a cherrybark oak genetic test planted on different soils in St. Landry Parish, Louisiana. They found that while growth differed on the two soils, the same families ranked highest in growth rate on both sites.

The present study was designed to compare the growth of six provenances across the Western Gulf region, develop preliminary seed

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movement guidelines, and determine the relative importance of provenance and family to cherrybark oak volume production.

Methods And Materials

Seed was collected in fall 1978 from 53 cherrybark oak trees in six provenances throughout the Western Gulf region. Bare-root seedlings were grown at the Texas Forest Service nursery near Alto, Texas, during the 1979 growing season, and outplanted into four genetic tests in early spring 1980. Thirty families were included in the first pair of tests, while 26 families were planted in the second pair of tests. Three families were included in all four tests.

Provenances represented in the four tests were: east-central Texas (ECTX), southeast Texas (SETX), north Louisiana (NOLA), south Arkansas (SOAR), southwest Mississippi (SWMS), and north Mississippi (NOMS). The first pair of tests were planted in Cass County, Texas, and St. Landry Parish, LA. The second two tests were established in Tyler County, Texas, and Warren County, Mississippi. Test locations and counties/parishes represented in each of the provenances are shown in Figure 1.

The first test, in Cass County, Texas (33°13'N, 94°35'W), was planted on a Marietta loam (fine-loamy, siliceous, thermic Fluvaquentic Eutrochrepts) in a minor stream bottom (B.L. Harris, personal communication). The second test was planted in St. Landry Parish, Louisiana (30°39'N, 91° 58'W), near the boundary between a Dundee silty clay loam (fine-silty, mixed, thermic Aeric Ochraqualfs) and a Baldwin silty clay loam (fine, montmorillonitic, thermic Vertic Ochraqualfs), adjacent to Bayou Wauksha on the Thistlethwaite Game Management Area. Cherrybark oak 50-year site index for the Dundee soil is listed as 32 m [Soil Conservation Service (SCS) 1986]; however, the actual site index at the test site is probably much lower due to poor drainage. Dicke and Toliver (1987) estimated that site index for an adjacent cherrybark oak plantation on a slightly better site ranged from 28.7 to 30.2 m. The third test was planted on a Spurger fine sandy loam (fine, mixed, thermic, Albaquultic Hapludalfs) (C.C. Wiedenfeld, personal communication) in the Neches River bottom in SE Tyler County, Texas (30° 40'N, 94°05'W). The fourth test was planted on a Memphis silt loam (fine-silty, mixed, thermic, Typic Hapludalf) (SCS 1964) in the loess bluffs in Warren County, Mississippi (32° 22'N, 90°49'W). All tests were mowed or disked for control of competing vegetation for at least 3 years after establishment . Volunteer trees were removed by hand as needed from the plantations.

Tests were plan ted in 10 randomized complete blocks. Bach family was represented in each block by a four-tree row plot . Height, dbh, and survival were determined for each tree in all four tests in fall 1989 after the 10th growing season. Individual tree volume was determined by the following formula adapted from Matney et al. (1985):

$$V = -.16877 + .032043*(D^2H),$$

where V = total tree volume/dm^3,
D = dbh/cm,
H = total height/m.

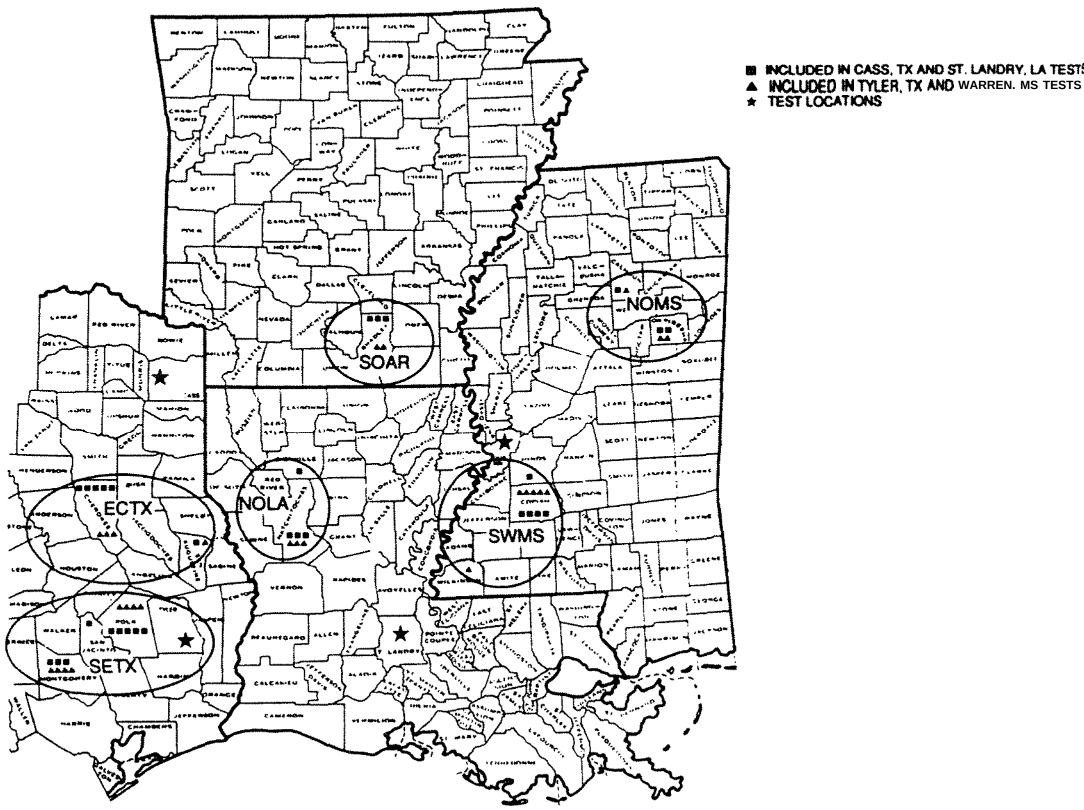

Figure 1. Provenances and locations of four cherrybark oak genetic tests planted in the Western Gulf region.

Survival, height, diameter, and volume data were subjected to analysis of variance. The SAS GLM procedure was used for all analyses (SAS Institute 1985). Means were separated with Duncan's multiple range test. Dead trees were excluded from height and diameter analyses but were included with a value of 0 in the volume analysis. Plot means were used in all analyses . Two replications of the Cass County test, one replication of the St. Landry Parish test, and one replication of the Warren County test were omitted from the analyses because of poor survival. Tests containing the same families were first analyzed in pairs to determine if a significant plantation x provenance interaction could be detected. Since no such interaction was found, tests then were analyzed individually to evaluate provenance- and family-within-provenance effects. In both models, provenance was considered to be a fixed effect; all other terms were treated as random effects.

Results And Discussion

Mean survival, height, and planted tree volume for the four genetic tests are presented in Table 1. The planting at Warren County, Mississippi, had the best growth, while planting in St. Landry Parish, Louisiana, had the slowest growth. The reason for these differences appears to be site-related: cherrybark oak site indices on Memphis silt loam range from 27.4 to 32.0 m at age 50 (SCS 1964), while the site in St. Landry Parish was too poorly drained for maximum cherrybark oak growth. Drainage also appeared to be the limiting factor at the Cass County, Texas, site when two replications died because of flooding in this test.

Table 1. Mean survival, height, and volume for four lo-year-old cherrybark oak genetic tests in the Western Gulf region.

county/ parish/state	Survival	Height	Volume
	percent	(m)	(dm^3)
Cass, Texas	84	8.0	25.3
St. Landry, Louisiana	69	6.1	9.8
Tyler, Texas	86	9.0	38.6
Warren, Mississippi	78	11.3	44.9

Provenance had significant effects on height and volume in all four tests (Table 2). Results of the diameter analysis were identical to those for height with respect to means ranking and significance, and are therefore not included in this paper. Provenance means of height and volume in the four tests are presented in Figures 2 and 3. The NOLA provenance consistently outperformed all other sources, while the NOMS source ranked last in height and volume in all four tests. No strong local source effect was detectable in the two tests which contained local sources (Tyler County, Texas, and Warren County, Mississippi). This stability of provenance rankings across such a wide variety of site conditions is somewhat surprising, although Dicke and Toliver (1987) reported stable family rankings for height in a 5-year-old cherrybark oak genetic test planted partly on a Dundee silty clay loam and partly on a Baldwin silty clay loam. Apparently, genetic factors which promote superior growth in cherrybark oak are relatively insensitive to site variation. Significant differences in survival between provenances occurred only in the St. Landry Parish, Louisiana, test, which was established on the poorest of the four sites (Table 2, Fig. 4). Interestingly, the north Mississippi source survived the best on this site, while survival for this provenance was near average on the other sites. A weak or negative relationship between survival on more severe sites and volume growth is not without precedent. Schoenike et al. (1982) reported on lo-year data from two genetic tests of southern red oak in which no obvious relationship existed between survival and height growth for provenances across the range of the species. Dicke and Toliver (1987) found families with high growth rates and high survival rates, as well as families with good growth and low survival on a poorly drained site. Genes which permit survival under challenging conditions may have no effect on, or be deleterious to, growth on more favorable sites.

Table 2. Analysis of variance for four lo-year-old cherrybark oak genetic tests in the Western Gulf region.

Source of variation	Survival df	Survival ms	Height df	Height ms	Volume df	Volume ms
			Cass County, Texas			
Rep	7	851.4*[1]	7	18.3 **	7	1844.5 **
Prov	5	678.4	5	6.6 *	5	864.2 **
Rep* Prov	35	417.7	35	2.1	35	148.4
Fam (Pr)	24	656.1*	24	4.1 **	24	518.9 **
Error	168	405.1	167	1.6	168	162.2
			St. Landry Parish, Louisiana			
Rep.	8	369.4	8	7.3 **	8	121.2 **
Prov	5	3884.6**	5	4.6 **	5	245.0 **
Rep * Prov	40	666.9	40	0.7	40	33.7
Fam (Pr)	24	1322.4**	24	2.8 **	24	88.3 **
Error	192	679.6	183	0.6	192	33.1
			Tyler County, Texas			
Rep	9	694.0*	9	16.2 **	9	1176.1 **
Prov	5	525.9	5	9.2 **	5	1845.1 **
Rep * Prov	45	408.8	45	0.9	45	151.9
Fam (Pr)	20	450.3	20	2.1**	20	570.4**
Error	180	316.9	179	1.1	180	231.6
			Warren County, Mississippi			
Rep	8	1515.4**	8	28.8 **	8	865.2
Prov	5	308.0	5	15.0 **	5	2331.1 **
Rep * Prov	40	323.0	40	2.3	40	374.0
Fam (Pr)	20	658.0	20	3.4*	20	1058.7 **
Error	160	458.4	159	2.0	160	480.2

[1] * = significant at the 5-percent level
** = significant at the l-percent level

Significant, family within-provenance effects occurred for height and volume in all four tests, and for survival in the two tests planted on sites with less-than-optimum drainage (Table 2). Family within-provenance accounted for 24 to 38 percent of the genetic variation in volume and 19 to 38 percent of the genetic variation in height in the four tests. All of the provenances except NOMS were represented in the top 20 percent of volume production by at least one family in one test. These facts suggest that both provenance and within-provenance variation should be considered in cherrybark oak tree improvement programs.

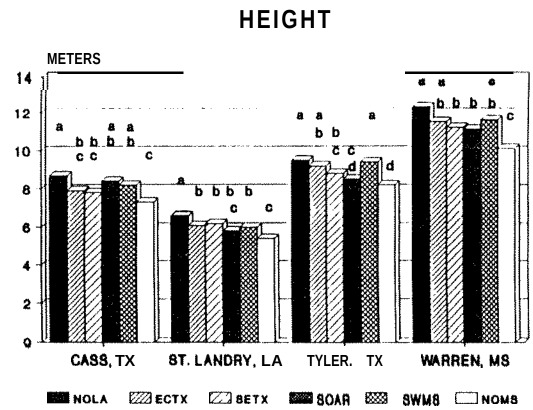

Figure 2. Mean 10-year height of six cherrybark provenances in four genetic tests planted in the Westem Gulf region. Means with the same letter are not significantly different at the 5-percent level according to Duncan's multiple range test.

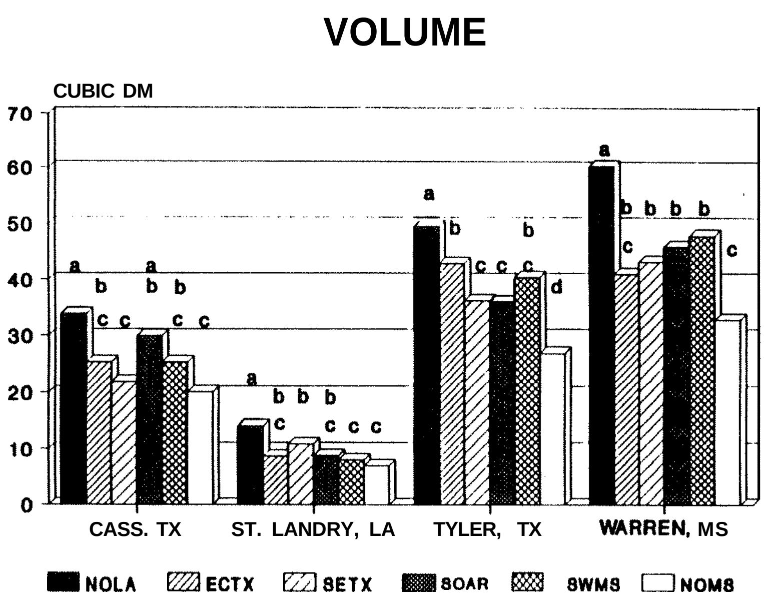

Figure 3. Mean 10-year volume of six cherrybark provenances in four genetic tests planted in the Western Gulf region. Means with the same letter are not significantly different at the T-percent level according to Duncan's multiple range test.

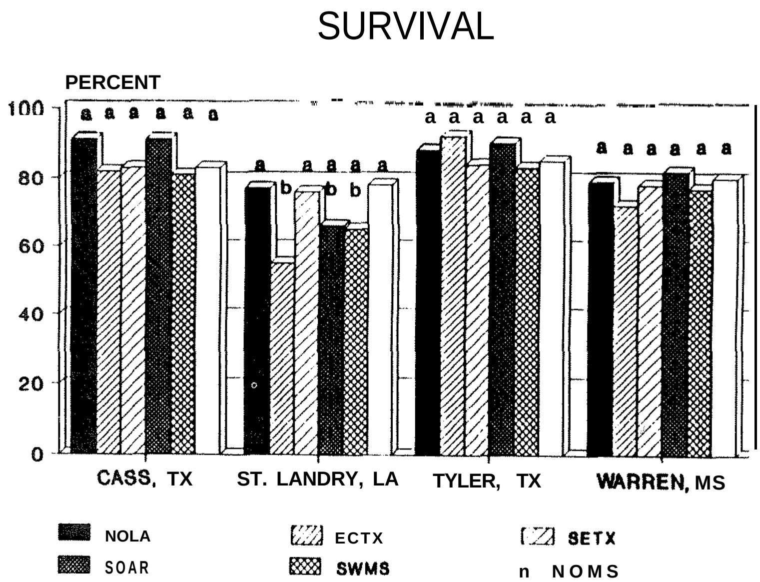

Figure 4. Mean 10-year survival of six cherrybark provenances in four genetic tests planted in the Western Gulf region. Means with the same letter are not significantly different at the E-percent level according to Duncan's multiple range test.

Conclusions

The following conclusions can be drawn from this study:

1. Until orchard seed becomes available, seed from NOLA, the north Louisiana provenance (Natchitoches and Bienville Parishes) should be used for artificial regeneration programs in the four regions represented by the genetic tests. Studies involving seed movement should be considered tentative until the tests on which they are based reach one-half rotation age.

2. Since relative performance of provenances varied little across planting sites, it appears that within the range of sites investigated genetic factors which allow rapid early growth are relatively insensitive to site conditions.

3. Inherited survivability appears to increase in importance on sites where survival is challenged. Greater survivability is not necessarily linked to individual tree growth in cherrybark oak.

4. Strong, consistent differences in performance of both provenances and families within provenance indicate that cherrybark oak improvement programs in the Western Gulf region should take provenance and individual family effects into account.

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FAMILY, SPACING, AND FAMILY-BY-SPACING EFFECTS ON LOBLOLLY PINE DURING FIVE YEARS AFTER PLANTING [1]

Samuel B. Land, Jr., Keith L. Belli, and Howard W. Duzan, Jr.[2]

Abstract. Seedlings from open-pollinated families of eight selected North Carolina trees and a Mississippi-Alabama commercial check were planted at three spacings (5 x 5, 8 x 8, and 10 x 10 ft) in east-central Mississippi. Results after 5 years indicated: (1) significant spacing effects for height at ages 3 and 5 and for dbh and limb diameter at age 5; (2) significant family differences at all ages for height, diameter, stem fusiform rust infections, limb diameter, and stem straightness; and (3) a significant family-by-spacing interaction for straightness. Families rated as faster growing in North Carolina were also faster growing in Mississippi, and families having smaller crowns in North Carolina had smaller limbs and straighter stems in Mississippi. The family-by-spacing interaction was associated with: (1) the commercial check, which decreased in straightness rank from the close spacing to the wider spacings; and (2) the crown size classification, where small-crown families increased in straightness and large-crown families decreased in straightness as spacing increased. The general absence of family-by-spacing interactions for other traits indicates that selections from progeny tests at close spacings should be valid at wider spacings.

Introduction

Competition among trees, the effect of this competition on stand development, and the genetic control of competition are not well understood. Spacing studies containing progeny families selected to represent contrasting growth and crown types might provide information important to: (1) an understanding of the biological basis of competition and (2) the enhancement of stand productivity. Such a study was established in 1985 for loblolly pine (*Pinus taeda* L.). Pertinent objectives for the present paper were to: (1) define effects of spacing on tree characteristics during the 5 years following planting; (2) evaluate performance in Mississippi (MS) of North Carolina (NC) families selected for "fast" and "slow" growth rates and for "small" and "large" crown sizes; (3) compare the NC-selected families with a nonselected local source for performance in east-central MS; and (4) determine if spacing-by-family interactions exist that will indicate the need to match particular family growth and crown types with particular spacings.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Professor and Assistant Professor, Dept. Forestry, Mississippi State Univ., MS; Research Station Manager, Weyerhaeuser, Columbus, MS. Approved for publication as Journal Article P-7606 of the Mississippi Agricultural and Forestry Experiment Station.

Methods

Open-pollinated progenies from eight selected trees in eastern NC and a commercial check from east-central MS and west-central Alabama (AL) (Lowndes and Kemper Counties, MS, and Fayette and Pickens Counties, AL) were provided by the Weyerhaeuser Company. The eight families were chosen based on 12-year-old progeny tests in NC to represent combinations of fast and slow growth rates with small and large crowns (Table 1). Seedlings were grown by Weyerhaeuser in leach tubes from December 20, 1984, to April 19, 1985, transported to the MS site in refrigerated trucks, and planted during April 22-May 7, 1985.

Table 1. Growth rate and crown size "types" of eight loblolly pine families from North Carolina.

	Type		Performance levels[a] (average for two families)		
Families	Growth	Crown	Height	Tree volume	Crown score
NC1 and NC8	Fast	Small	68.5	60.0	72.0
NC4 and NC7	Fast	Large	65.5	72.5	46.0
NC3 and NC6	Slow	Small	45.0	45.5	61.0
NC2 and NC5	Slow	Large	37.5	37.5	43.5

[a] Performance levels (PL) indicate how much the mean for all progenies from the parent tree exceeded or fell below the plantation mean for the progeny test. If the mean progeny value was two or more standard deviations below the test mean, PL was zero. If the mean was two or more standard deviations above the test mean, the PL was 100. A progeny mean that was equal to the test mean would get a value of 50. The PL values from 6-15 test sites in NC were averaged to give the values shown here. The normal range for family PL values in the Weyerhaeuser program is 30-70.

The planting site is located on the John Starr Memorial Forest (Mississippi State University school forest), Winston County, MS (33°16'N latitude, 52° 40'W longitude). This is in the "Interior Flatwoods" land resource region. The soil is an acidic, silty clay loam that has a fragipan and is somewhat poorly drained. Site index for loblolly pine at age 25 is 75 ft.

Two adjacent fields were used for the study. Soil series were the same, but one was a recently cleared, site prepared tract which formerly contained a 75-year-old pine stand; the other was an old-field. Data from the two fields were combined for analyses. A randomized complete block design with eight replications (four on each field) was used. Treatments consisted of three spacings (5 x 5, 8 x 8, and 10 x 10 ft) and nine families (eight NC families and the commercial check). These treatments were arranged in a split plot design with spacings as whole units. However, each plot spacing occupied the same size (1.14 ac) of land area to avoid differences in site variation, so more trees per family were planted in the closely spaced plots than in the widely spaced plots. Analyses of variance were therefore conducted on family-plot means within spacing whole units. A mixed model was used, with replication effects considered random and spacing and family effects considered fixed. Duncan's New Multiple Range Test was used to test differences among ranked treatment means at the 0.05 probability level. The total study consisted of 26,026 planted trees (counting border rows) and occupied 27.5 ac.

Herbicides were used to control herbaceous and hardwood competition during the first 2 years. On April 10-16, 1985, (immediately before planting) a mixture of Velpar™ (½ lb/ac a. i.), Oust™ (2 oz/ac), and Roundup™ (1 percent a.i.) was applied by backpack sprayer in 3.5-ft-wide bands centered on the flagged rows to be planted. During July 8-12, 1985, Garlon™ mixed with diesel fuel (3 percent concentration = 450 ml Garlon/gal of diesel fuel) was spot sprayed on the bases of hardwood sprouts. A Velpar-Oust mixture (same rates as above) was sprayed in a 3.5-ft band over the rows of trees during March 10-12, 1986, before the start of the second growing season.

Measurements of survival were taken in September 1985, 4 months after planting. One-year survival and height were measured during December 1985 to February 1986. In the winter of 1987-88 measurements were made for 3-year survival, height, stump diameter (6 inches aboveground), number of fusiform cankers (Cronartium fusiforme Hedg. and Hunt) on the stem, and number of fusiform infections (up to nine) on the limbs. Fifth-year measurements taken during December 1989 to January 1990 included survival, height, diameter at breast height (dbh), percentage of stem circumference affected by the largest fusiform canker, diameter (1 inch from the stem) of the largest non-fusiform limb on the 4-ft stem section between 3- and 7-ft heights, and a subjective stem straightness code. Straightness codes were:

1 = straight,
2 = slightly crooked due to slight zig-zag between successive limb whorls or to small sweep from a slightly leaning tree, but little evidence of cork-screw spiral in the top of the stem or in limbs,
3 = moderately crooked due to moderate zig-zag or sweep (< 4-inch deviation from a straight line in the bottom 8 ft), or moderate cork-screw spiral in the top, and
4 = very crooked due to excessive zig-zag or sweep (> 4-inch deviation), or excessive cork-screw spiral in the top.

Results And Discussion

After 5 years, survival was 95 percent, mean height was 15 ft, mean dbh was 2.5 inches, and 16 percent of the trees had stem fusiform infections. The largest limb, between 3- and 7-ft heights on the stem, had a diameter equal to one-third of the dbh, and stem straightness was slightly better than the midpoint of the four-point grading scale (Table 2). The high survival, rapid growth, and high incidence of fusiform infection enhanced the ability of the study to detect spacing and family effects by age 5.

Table 2. Significance of spacing effects, family effects, and spacing-by-family interactions for traits during the first 5 years after planting (eight NC families and a MS/AL commercial check).

Trait	Study mean	F-test significance (PR > F)[a] Spacings	Families	SxF
Survival	(percent)			
4 months	99.4	.5066	.2132	.6248
1 year	99.0	.4400	.2718	.6830
3 years	96.8	.7611	.0532	.9372
5 years	95.4	.8211	.0762	.5823
Height	(ft)			
1 year	1.2	.5340	.0001 **	.9395
3 years	6.5	.0006 **	.0001 **	.8722
5 years	15.0	.0001 **	.0001 **	.8096
Diameter	(inch)			
3-year stump	1.44	.1100	.0001 **	.7664
5-year dbh	2.48	.0020 **	.0001 **	.7969
Stem fusiform	(percent)			
3 years	9.9	.1079	.0001 **	.9702
5 years	16.3	.8457	.0001 **	.8131
Largest limb	(at 3-7 ft)			
5-year dia (inches)	0.74	.0008 **	.0001 **	.5562
5-year dia/dbh ratio	0.31	.0033 **	.0001 **	.2811
Stem straightness[b]				
5-year straightness	2.24	.6844	.0001 **	.0204 *

[a] Probabilities between 0.01 and 0.05 were considered significant (*), and probabilities less than or equal to 0.01 were considered highly significant (**).

[b] Straightness codes: 1= straight; 2= slightly crooked; 3= moderately crooked; 4= very crooked.

Spacing Effects

Spacing did not influence survival, stem fusiform infections, nor straightness during the first 5 years (Table 2). The lack of effect on survival indicated that competition among trees, even at the 5 x 5-ft spacing, had not reached the point of causing mortality by age 5. Two factors that might influence the frequency of stem fusiform infections [(1) frequency of occurrence of the alternate host (red oaks) and/or (2) increased humidity in the understory of a closed stand (permitting longer life of basidiospores)] were apparently unaffected by spacing. Chemical control of hardwoods and the small plot sizes relative to effective flight distances of basidiospores could have been responsible for this result. Surprisingly, close spacing did not improve straightness. Shorter, widely-spaced trees in a Weyerhaeuser spacing trial in eastern NC were more susceptible to tip moth (*Rhyacionia* spp.) than were taller, closely spaced trees.[1] The greater incidence of tip moth attacks on terminal buds at the wider spacings might have been expected to reduce straightness in those spacings, bit such was apparently not the case.

Close spacing significantly increased height growth at ages 3 and 5 years, but not at age 1 (Table 3). Mean height in the 5 x 5-ft spacing was 6.7 percent greater than that in the 8 x 8-ft spacing, and 10.5 percent greater than that in the 10 x 10-ft spacing at age 3. By age 5 these differences had increased to 7.5 and 11.1 percent, respectively.

Table 3. Effects of spacing on height with increasing stand age.

Stand age	Spacing-ft		
	5 x 5	8 x 8	10 x 10
(yr)	(height/ft)		
1	1.20[a]	1.21	1.19
3	6.86	6.43	6.21
5	15.92	14.81	14.33

[a] Means underlined by the same line were not significantly different at the 0.05 probability level according to Duncan's New Multiple Range Test.

The greater height growth at close spacings might be due to differences in weed competition and/or to differences in net photosynthesis and carbon allocation in the crown. Strip spraying with herbicides removed more of

[1] Unpublished post-conference tour book, IUFRO Working Parties on Breeding Theory, Progeny Testing, and Seed Orchards, October 18-23, 1986, hosted by the North Carolina State University-Industry Cooperative Tree Improvement Program, School of Forest Resources, Box 8002, Raleigh, NC 27695-8002.

the total herbaceous weed cover on an area basis for trees planted at 5 x 5-ft spacing than for trees planted at the 8 x 8- or 10 x 10-ft spacings. The greater amount of weed competition at the wider spacings, even though the weeds were 2 ft or more away from the trees, might have reduced the height growth. However, a similar trend of increased height growth at close spacings was observed in a nearby study (Nance et al., 1983), where no herbicides were used with loblolly pines planted in a Nelders wheel design. Also, there was no differential competition effect on first-year height growth in the present study. These facts suggest that the spacing effects on height growth probably involve more than just differences in weed competition. Enhanced height growth at the close spacing may be due to increased net photosynthesis rates in the upper canopy during crown closure, as found by Nowak et al. (1990) in the tops of unthinned loblolly pines. Much of the carbon from that enhanced photosynthesis is probably allocated to nearby limb and terminal growth in the top of the tree, which would be consistent with results of Cregg (1990) for loblolly pine branches. However, the stimulation effect of close spacing is probably temporary. Results by Balmer et al. (1975) and unpublished results from a 20-year-old loblolly spacing trial located near the present test site (Shelton and Switzer 1980) indicated that 9 x 10- and 10 x 10-ft spacings had greater mean heights than did 5 x 5- or 6 x 6-ft spacings by age 15-20 years. The difference in height at 15-20 years was probably caused by the presence of more short, suppressed trees in the close spacings.

Dbh, largest limb diameter, and ratio of largest limb diameter to dbh were all significantly smaller at age 5 in the 5 x 5-ft spacing than in the two wider spacings (Table 4). There were no significant differences between the 8 x 8- and 10 x 10-ft spacings. Apparently, competition among trees (as expressed by reduced cambial growth) had started only in the 5 x 5-ft spacing by age 5. The limb-diameter results suggest that the lower limbs in the 5 x 5-ft spacing had already been shaded by crown closure to the point that they were producing less new needle area and less photosynthate for limb growth than was occurring for upper canopy limbs. Recent reports by Holeman et al. (1990) and Cregg (1990) have documented that such effects do occur for shaded branches in the lower canopy of loblolly pine trees. Therefore, limbs between 3- and 7-ft aboveground (the lower half of the crown) in the 5 x 5-ft spacing were contributing very little to both limb diameter and stem diameter growth, and current annual growth in dbh had already begun to decline by age 5.

Family Effects

The families did not differ significantly in survival during the first 5 years (Table 2). This indicates that the NC families were adapted to survive in the short-term at the MS site, even though the 5-year period contained an ice storm (February 1989), unusual cold (-2°F on December 23, 1989), four drier-than-average growing seasons (a long-term average of 25 inches for the 6-month period April-September, but the years 1985-88 were -2.6, -7.0, -11.0, and -5.9 inches below average), and one wetter-than-average season (+12.6 inches for 1989).

Families differed significantly in heights at ages 1, 3, and 5 years, but the first-year rankings were not indicative of third- and fifth-year family ranks (Tables 2 and 5). The commercial check and families NC5 and

NC6 were consistently shortest in height at all ages, but only one of the tallest three families at age 5 was among the tallest three at age 1. Third-year rankings were good indicators of fifth-year rankings, however. The tallest three and shortest three families were consistent across spacings at each age, indicating that the 5 x 5-ft spacing was no better or

Table 4. Effects of spacing on dbh, largest limb diameter, and largest-limb-diameter-to-dbh ratio at 5 years after planting.

Trait	Unit	Spacing-ft 5 x 5	8 x 8	10 x 10
Dbh	inch	2.37	2.53"	2.54
Largest limb dia -between 3-7 ft	inch	0.64	0.77	0.83
Largest limb dia/dbh	ratio	0.28	0.32	0.34

[a] Means underlined by same line were not significantly different at the 0.05 probability level according to Duncan's New Multiple Range Test.

worse than the 10 x 10-ft spacing for early selection through age 5. Thus, these closely-spaced tests could improve effectiveness of early selection as proposed by Campbell et al. (1986) and Franklin (1989), by culling large base populations on less land area. However, close spacing at 5 x 5 ft would not give a correct ranking for fifth-year heights any earlier (at age 1) than wider spacings. The present results suggest that selections may be made at age 3 or age 5 for 5-year height growth. Selections from progeny tests with spacings ranging 5 x 5 and 10 x 10 ft should be applicable to the entire range of commercial spacings between these extremes.

Families also differed significantly in stem diameters and stem fusiform infections at ages 3 and 5 years, and in limb diameter and stem straightness at age 5 (Tables 2 and 6). The commercial check was: (1) among the three poorest families for fifth-year dbh; (2) intermediate among the families in percent of trees with stem fusiform infections; (3) largest of all families in limb diameter relative to dbh; and (4) among the three poorest families for stem straightness. These results and those for height indicate that selection in NC and/or use of the eastern NC provenance in east-central MS can result in increased height and diameter growth, smaller limb size, and straighter stems than the local, unselected seed source during the first 5 years after planting. An eastern-NC provenance (Onslow County, NC) planted for the Southwide Pine Seed Source Study in 1953 on a site within 1 mi of the present study was among the three best sources at age 20 and was better than the local source.[1] The one problem for the Onslow County source was susceptibility to fusiform rust, but this problem can be overcome by selection among NC families (as indicated in Table 6).

Table 5. Ranked family means for height at ages 1, 3, and 5 years after planting on an interior flatwoods site in east-central MS (average heights for three spacings).

After 1 year		After 3 years		After 5 years	
Family[a]	Height	Family	Height	Family	Height
	(ft)		(ft)		(ft)
NC7	1.26 A[b]	NC1	7.1 A	NC1	15.9 A
NC8	1.24 AB	NC4	6.8 B	NC4	15.8 A
NC4	1.23 AB	NC3	6.6 c	NC2	15.4 B
NC3	1.20 BC	NC2	6.6 CD	NC7	15.2 BC
NC2	1.20 BC	NC7	6.5 CD	NC8	15.0 BCD
NC1	1.19 BC	NC8	6.5 CD	NC8	15.0 CD
NC6	1.19 BC	NC6	6.4 D	NC6	14.7 D
NC5	1.17 c	CCK	6.2 E	CCK	14.2 E
CCK	1.11 D	NC5	5.9 F	NC5	14.0 E

[a] NC represents families originating in eastern North Carolina; CCK represents a commercial-check bulk seedlot from trees in east-central MS and west-central AL,.

[b] Means at the same age followed by the same letter were not significantly different at the 0.05 probability level according to Duncan's New Multiple Range Test.

Further evidence that selection in NC tests can affect performance in MS is provided by the MS means for the NC progeny-test classifications of growth rate and crown size (Table 7). The four families classified for "fast" growth rate in NC (Table 1) had significantly taller trees, larger diameters, less fusiform stem infections, larger limbs (but smaller limb diameter relative to dbh), and slightly more crooked stems than the four "slow" growth families when grown in MS. Crown-size classification was not related to height and diameter at age 5 in MS, but “small crown” families had smaller limb diameters relative to dbh, straighter stems, and a slightly greater percentage of trees with stem fusiform infections than “large crown" families. Thus, selection for growth in NC was effective for growth in MS, and selection for crown size in NC was effective for limb size and

[1] Uunpublished file data, Mississippi State Univ., Dept. Forestry.

straightness in MS. Fusiform resistance was not related directly to either of these selection criteria in NC, so the differences in MS must be interpreted with caution. One might have expected the "fast" growth and "large crown" families to have more fusiform infections, because they would have more surface area in a succulent, susceptible stage at any given time. The reduced infection of these classes implies independent genetic control of the different traits, so that families with both fast growth and high resistance can be selected. Finally, "large-crown" families tended to have more crooked stems in MS at age 5 than "small-crown" families. Perhaps the large limbs and crooked stems are both a result of reduced apical dominance of the stem's terminal bud, so that the limb-stem junction distorts the stem's straightness. Another possibility is that large limbs predispose the tree to more breakage, which would reduce stem straightness.

Family-by-Spacing Effects

The only family-by-spacing interaction was for stem straightness (Table 2). This scarcity of interaction with spacing has also been reported by Campbell et al. (1986). They found interactions only for 5-year height

Table 6. Family means for fifth-year dbh, percent stem rust infection, limb size, and stem straightness on an interior flatwoods site in east-central HS (averages for three spacings).

	Family means and Duncan's tests			
Family[a]	Dbh	Stem rust	Limb size ratio	Straightness[b]
	(inch)	(percent)		
NC1	2.60 A[c]	10.3 D	.290 D	2.17 B
NC8	2.43 CD	12.4 D	.298 CD	2.10 c
NC4	2.62 A	9.9 D	.298 CD	2.39 A
NC7	2.53 B	9.1 D	.315 B	2.35 A
NC3	2.50 BC	29.0 A	.315 B	2.21 B
NC6	2.49 BC	16.5 C	.297 CD	2.18 B
NC2	2.48 BC	22.6 B	.304 c	2.24 B
NC5	2.26 E	16.9 C	.319 B	2.21 B
CCK	2.41 D	20.1 BC	.369 A	2.35 A

[a] NC represents a NC family; CCK represents MS/AL commercial check.

[b] Straightness codes : 1= straight; 2= slightly crooked; 3= moderately crooked; 4= very crooked.

[c] When two family means for the same trait (i.e., within the same column) were followed by the same letter, they were not significantly different at the 0.05 probability level (according to Duncan's New Multiple Range Test).

Table 7. Ranked, fifth-year tree size, limb-size, rust infection, and straightness for two growth-rate classes and two crown-size classes of eight loblolly pine families from eastern NC.

Five-year treatment means and Duncan's tests	Growth rate		Crown size	
	Slow	Fast	Small	Large
Number families		4	4	4
Height (ft)	(144.8 [a]	15.5)	(15.2	15.1)
Dbh (inch)	(2.43	2.54)	(2.50	2.47)
Stem fusiform (percent)	(21	10)	(17	15)
Largest limb (at 3-7 ft)				
1. diameter (inch)	(0.72	0.74)	(0.72	0.74)
2. diameter/dbh ratio	(.309	.300)	(.300	.309)
Straightness[b]	(2.21	2.25)	(2.17	2.30)

[a] Means underlined by the same continuous line within parentheses were not significantly different at the 0.05 probability level according to Duncan's New Multiple Range Test.

[b] Straightness codes: 1= straight; 2= slightly crooked; 3= moderately crooked; 4= very crooked.

and 9-year volume in Douglas-fir (*Pseudotsuga menziesii* Franco), and those interactions were attributed to measurement scale. Magnussen and Yeatman (1987) reported statistically significant but unimportant interactions for stem and limb diameters of jack pine (*P. banksiana* Lamb.).

One cause of the family-by-spacing interaction for straightness was a family rank change between the 5 x 5-ft spacing and the wider spacings for the commercial check, and for family NC6 (Table 8). The commercial check was relatively straight at the 5 x 5-ft spacing and very crooked at the two wider spacings. The NC6 family (slow growth and small crown) was moderately crooked at the 5 x 5-ft spacing and fairly straight in the wider spacings. The commercial check was unselected and may represent the plasticity of straightness in nature, where many extremes in spacing may be experienced and straightness under high densities in seedling stands may confer an advantage. Family NC6 was probably selected for straightness in a test under one of the wider spacings. At the 5 x 5-ft spacing its slow growth quickly placed many of its trees in the intermediate crown class, where poor growth may have contributed to crooked stems.

A second cause of the family-by-spacing interaction was a family "crown-size" by spacing interaction for the NC families (Table 9). In all spacings the "small crown" families were straighter than the "large-crown" families. However, the straightest trees were found in the 10 x 10-ft spacing for the "small-crown" families, while the most crooked trees were in the same spacing for the "large-crown" families. One possible explanation would be that where adequate sunlight reached the lower half of the crown (wide spacing), "competitor" genotypes (large-crown families) allocated more of the total tree's photosynthate to lateral branches. Hence, they would lose some of their apical dominance and develop more crooks or "zig-zag" patterns between successive limb whorls on the stem (because of the large limbs) than "crop tree" genotypes (small-crown families).

The lack of family-by-spacing interactions for height, diameter, stem fusiform infection, and limb size indicates that selections in progeny tests up through age 5 should be applicable over a wide range of plantation spacings. This means that selections from progeny tests established at relatively close spacings would be appropriate in wide spacings on some industrial lands or in closer spacings on small private ownerships (where spacing is dictated by degree of site preparation and control of competing vegetation).

Summary

A large spacing study with eight NC families and a local commercial check in east-central MS had 95 percent survival, a mean height of 15 ft, a mean dbh of 2.5 inches, and a 16 percent stem infection rate by fusiform rust after five growing seasons. The three spacings used were 5 x 5, 8 x 8, and 10 x 10 ft. These spacings had no influence on survival, stem rust infections, or stem straightness during the first 5 years. However, the closest spacing significantly increased third- and fifth-year height growth and decreased fifth-year dbh and largest limb diameter. The stimulation of height growth is probably temporal, as older tests indicate that the wider spacings eventually have the taller mean tree heights.

The NC families survived as well as the local commercial check and exceeded that check (with one exception) in height growth during the first 5 years after planting. First-year family rankings for height were not indicative of third- and fifth-year rankings, nor was the 5 x 5-ft spacing any better for first-year rankings than the two wider spacings. Early selection in the range of spacings used here should not be based on measurements before age 3. The unselected commercial check, as compared with the selected NC families, was among the poorest families for 5-year dbh, had the largest limb diameters relative to dbh, was among the poorest families for stem straightness, and was intermediate in percent stem rust infections. Progeny-test classifications of the NC families for growth rate and crown size in NC were related to family performance in MS. Fast-growth families in NC had taller trees and larger diameters than slow-growth families when planted in MS. Small-crown families in NC had smaller limb diameters and straighter stems than large-crown families when grown in MS. These results indicate that selection in NC and/or use of the eastern NC provenance were effective in providing gains in MS.

The only significant family-by-spacing interaction was for stem straightness. One cause of the interaction was family rank changes between the 5 x 5-ft spacing and the two wider spacings for the commercial check and one of the slow-growth, small-crown NC families. The NC "crown-size" classification, but not the "growth-rate" classification, contributed to the interaction for the NC families. The straightest trees were found in the 10 x 10-ft spacing for the "small-crown" families, but the most crooked

Table 8. Ranked family means for stem straightness of 5-year-old loblolly pines planted in each of three spacings.

5 x 5-ft		8 x 8-ft		10 x 10-ft	
Family	Straightness[a]	Family	Straightness	Family	Straightness
NC4	2.42 A[b]	CCK	2.37 A	CCK	2.45 A
NC7	2.37 A	NC7	2.35 A	NC4	2.42 A
NC6	2.26 B	NC4	2.32 AB	NC7	2.33 AB
NC3	2.26 B	NC3	2.22 BC	NC5	2.28 BC
NC2	2.24 B	NC2	2.21 BC	NC2	2.28 BC
CCK	2.24 B	NC1	2.18 CD	NC3	2.16 CD
NC5	2.20 BC	NC5	2.16 CD	NC1	2.15 CD
NC1	2.19 BC	NC6	2.15 CD	NC6	2.12 D
NC8	2.11 c	NC8	2.07 D	NC8	2.10 D
Average	2.26		2.22		2.25

[a] Straightness codes: 1= straight; 2= slightly crooked; 3= moderately crooked; 4= very crooked.

[b] Means within a column followed by the same letter were not significantly different at the 0.05 probability level according to Duncan's New Multiple Range Test.

Table 9. Stem straightness means for spacings by family crown-size classes in a 5-year-old spacing study of NC loblolly pine families in MS.

Spacing	Family crown size classifcation	
	Small	Large
5 x 5	2.21[a]	2.31
8 x 8	2.16	2.26
10 x 10	2.13	2.33

[a] Straightness codes: 1= straight; 2= slightly crooked; 3= moderately crooked; 4= very crooked.

trees were found in the same spacing for the "large-crown" families. The general absence of spacing-by-family interactions for other traits indicates that selections from progeny tests grown at one spacing will be suitable for use at other spacings.

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EFFECT OF SITE PREPARATION, PLANTING DENSITY, AND SOIL DRAINAGE ON JUVENILE WOOD FORMATION OF SLASH PINE [1]

Alexander Clark III, Joseph R. Saucier, and Terry I. Sarigumba [2]

Abstract. Slash pine (*Pinus elliottii* Engelm. var *elliottii*) plantat ions, established on several Coastal Plain soils in 1958 to evaluate the effects of mechanical site preparation treatments and initial planting densities on wood production, were sampled to determine whether these treatments affected juvenile wood formation and wood quality at breast height. Age of transition from juvenile to mature wood was not significantly affected by planting density and averaged 8 years. On intensively prepared subplots, juvenile wood was produced 2 years longer on moderately well drained soil than on poorly drained soil. At age 30, specific gravity of whole cores, juvenile wood, and mature wood at breast height did not vary significantly with site-preparation treatment or between the 6 x 6- and 6 x 12-ft spacings. Whole-core specific gravity of trees planted at 12 x 12 ft was significantly higher than that of trees planted at 6 x 6 ft. Diameter of the juvenile core generally increased with increased spacing and intensity of site preparation.

Introduction

Fast-growing southern pine plantations contain a higher proportion of juvenile wood than older natural pine stands because of early rapid growth and shorter harvest cycles. Clearcut pine timberlands often are intensively prepared for planting to improved stand establishment. Increased early growth due to mechanical site preparation is well documented (Shultz 1973, Mann and McGilvray 1974, Pritchett and Smith 1974, Terry and Hughes 1975, Derr and Mann 1977, Burger and Pri tchett 1988). The consensus among these researchers is that increased early growth is due to improved soil moisture conditions, better aeration, and more available nutrients. There is a lack of information about the effects of mechanical site preparation on the growth pattern, proportion, and quality of juvenile wood of southern pines.

Juvenile wood has lower specific gravity (SG) and shorter tracheids, with thinner walls, larger fibril angles, and less alpha cellulose than mature wood (Thomas 1984). Pulp yields from juvenile wood are lower and building products containing juvenile wood are weaker (Senf t et al., 1985; Bendtsen and Senft 1986; Pearson and Gilmore 1980; Pearson 1988) and more prone to warp, creating problems for manufacturers and consumers (Quarles and Erickson 1987).

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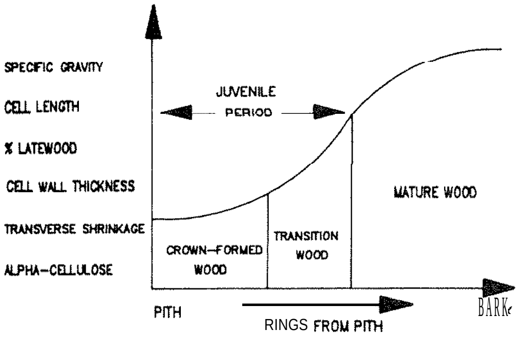

Figure 1. Schematic diagram of radial change in wood properties with age from pith and the pattern of maturation.

A radial cross-section of a pine stem contains three zones of wood (Fig. 1): (1) core or crown-formed wood, which is produced by immature cambium in the vigorous crown and has anatomical, chemical, and physical properties substantially different from mature wood; (2) transition wood, in a zone where wood properties are changing rapidly before wood reaches maturity; and (3) mature wood. In the spring, radial growth begins at the apex of the bole in the vigorous crown (Wareing 1958, Zahner 1963) and progresses with time to the base of the tree. Thus, more thin-walled earlywood (juvenile) tissues and wider rings of earlywood are produced in the upper bole than in the lower bole. The transition to thick-walled latewood (mature) tracheids occurs first near the base of the bole, farthest from the source of auxins, and proceeds upward as moisture stress increases and translocation of auxins down the bole decreases (Zahner 1963, Larson 1969). As trees grow older and taller and stands close, lower branches cease to be vigorous, and the lower boundary of the active crown moves up the stem. Therefore, there is a core of crown-formed wood surrounded by a band of transition wood from the butt to the merchantable top of the tree (Paul 1957; Zobel et al., 1959). Both crown-formed and transition wood are commonly referred to as juvenile wood.

Recently, Clark and Saucier (1989) showed that planting density significantly influences the proportion of stem basal area in juvenile wood but not the age of transition from juvenile to mature wood. They also showed that the juvenile period does not differ between slash (Pinus elliottii Engelm. var elliottii) and loblolly pine (P. taeda L.) when the species are planted at the same location, but does vary withgeographic location. On a poor sandy-loam site on the Coastal Plain of southeastern Mississippi, where nutrients rather than moisture limit growth, cultivation plus fertilization significantly increased growth but did not affect the date of transition from juvenile to mature wood in loblolly or slash pine (Clark and Schmidtling 1989). The results of these studies and earlier work by Zahner (1963), indicate that length of juvenile period is influenced more by soil-moisture relations than by nutrient availability or by inherent species traits.

The study described here was established in 1958 to evaluate the effects of different mechanical site preparation treatments and initial planting densities on the productivity of slash pine on different Coastal Plain soils. At age 30, the trees provided an excellent opportunity to examine the effects of treatments on juvenile wood formation and wood quality. The study was established by Brunswick Pulp Land Company on six soil types ranging from moderately well drained to poorly drained soils in southeast Georgia. On each site, 14 1-ac plots were delineated and randomly assigned one of seven planting spacings, ranging from 6 x 6 to 12 x

12 ft. Each 1-ac plot was divided into four subplots and each subplot was assigned a site preparation treatment. The site preparation treatments were:

Control-- no mechanical site preparation treatment except broadcast burning in May 1957

Scalp-- a Mathis fireline plow pushed out debris and l-2 inches of topsoil after broadcast burning in December 1957

Bed-- burned in May 1957 and plowed strips were prepared immediately after burning. Furrowed strips were made with a Mathis fireline construction plow by first throwing out the soil on row centers. These furrowed strips were then pulled in twice with an Athens fireline maintenance harrow, once in June and again in August 1957

Harrow-- burned in May 1957 and immediately harrowed with a 7-f t Rome offset harrow then reharrowed in August 1957.

Each 1-ac plot was replicated twice on each soil type. In January and February 1958, 1-O slash pine seedlings were planted with a dibble.

Numerous publications have documented the results of this study at various developmental stages (Worst 1964; May et al., 1973; Sarigumba and Anderson 1979; Sarigumba 1984; Dickens et al., 1989). Survival, diameter, height, fusiform rust incidence, volume growth, and projected volume growth have been discussed in these various papers. Here we examine the effects of mechanical site preparation and planting density on juvenile wood formation and wood SG.

Materials And Methods

In this study, the four site-preparation treatments, the 6 x 6-, 6 x 12-, and 12 x 12-ft spacings, and two soil types were analyzed. The soils were: (1) moderately well drained Orsino, which is a sandy siliceous, uncoated Spodic Quartzipsamment; and (2) a somewhat poorly drained to poorly drained Mascotte, which is a sandy over loamy, siliceous Ultic Haplaquod.

In the winter of 1988, 30 years after planting, two increment cores 12 mm in diameter, were removed at breast height from 20 randomly selected trees per spacing, site-preparation treatment, and location. A total of 240 trees were sampled per soil type.

In the laboratory, one increment core from each tree was separated into 2-year segments from the pith to bark. The unextracted SG of each 2-year segment was determined based on green volume and ovendry weight. The second core from each tree was dried, glued into a slot ted core holder, and surface-sanded. Width of earlywood and latewood were measured to the nearest 0.01 mm under a 65x microscope with a digitizing stage.

The age at which transition from juvenile to mature wood occurred was estimated to the nearest 2 years based on visual examination of plots of ring SG over rings from pith. The point at which the rate of increase in ring SG slowed was considered the point of transition from juvenile to mature wood. Weighted SG of the juvenile wood and the mature wood zones were then determined by weighting segment SG by segment basal area for the rings included in the juvenile and mature zones. A split-plot analysis of variance was performed on subplot means to determine if treatment means differed significantly. Results of Tukey's Studentized Range Tests were the criteria for separating treatment means (α = 0.05). Tests were performed to examine the effects of spacing and site-preparation on tree dbh, whole-core SG, mature-wood SG, juvenile-wood SG, mature-wood latewood content, juvenile-wood core diameter, and proportion of tree basal area in juvenile wood.

Results And Discussion

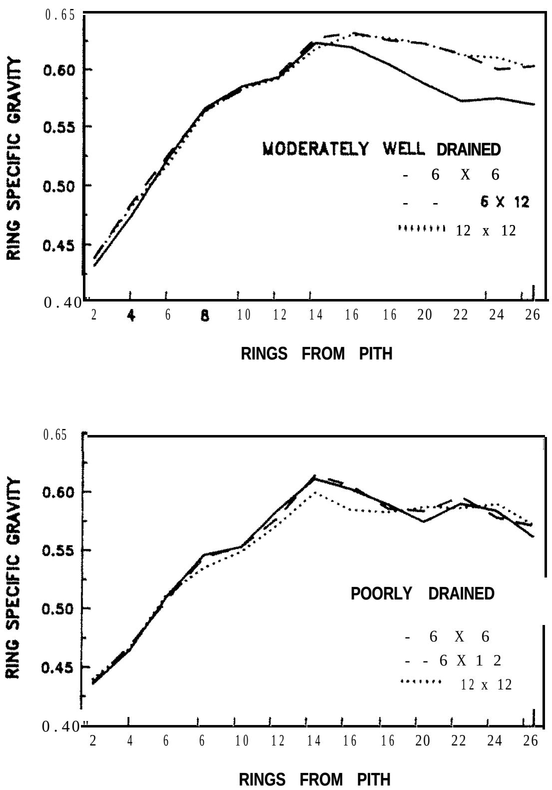

Figure 2. Effect of spacing on ring specific gravity and length of juvenility for slash pine planted on a moderately well drained and poorly drained soil.

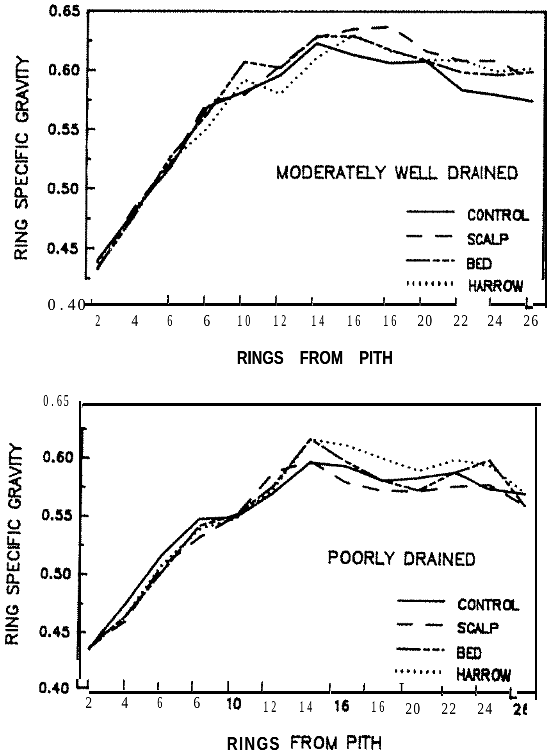

Figure 3. Effect of site-preparation treatments on ring specific gravity and length of juvenility for slash pine planted on a moderately well drained and poorly drained soil.

The graphic plots of SG over rings from the pith by spacing (Fig. 2) show that spacing had no effect on age of transition from juvenile to mature wood on either soil type. The plot of SG over rings from the pith by site-preparation treatments (Fig. 3), however, suggests that bedding and harrowing treatments increased the juvenile period on the moderately well drained soil. On the poorly drained soil, juvenile wood was produced for the first eight rings for all site-preparation treatments. On the moderately well drained soil, juvenile wood was produced for the first eight rings on the control and scalped subplots and for the first 10 rings on beded and harrowed subplots.

Based on Figures 2 and 3, the juvenile period was estimated for each soil, spacing, and site-preparation treatment (Tables 1 and 2).

Table 1. Juvenile period for each soil, spacing, and site preparation treatment.

Soil and spacing	Site preparation treatment			
	Control	Scalp	Bed	Harrow
	Number rings in juvenile zone			
Moderately well drained				
6 x 6	a	a	10	10
6 x 12	a	a	10	10
12 x 12	a	a	10	10
Poorly drained				
6 x 6	a	a	a	a
6 x 12	a	a	a	a
12 x 12	a	a	a	a

Table 2. Average dbh of trees sampled, by spacing and site preparation treatments.

Spacing	Site-preparation treatment			
	Control	Scalp	Bed	Harrow
-ft-	- - - - - - dbh (inch) - - - - - -			
6 x 6	7.0	7.1	6.8	6.9
6 x 12	7.8	7.9	7.8	8.1
12 x 12	8.5	8.6	8.8	9.6

Trees sampled for juvenile wood analys is displayed the same response to spacing and site-preparation treatments at age 30 as reported by Sarigumba (1984) for all trees at age 25. The dbh of trees increased significantly (Table 3) with increased spacing. At 12 x 12-ft, trees on harrowed subplots were significantly larger than those on the scalped and control subplots. Listed below are the average dbh of trees sampled by spacing and site-preparation treatment.

Since spacing and site-preparation treatments were not replicated on the same soils at different locations, no attempt was made to test for significant differences between soils. Plots of SG over rings from the pith by soil type (Fig. 4) show average ring SG of trees on the poorly drained soil to be consistently below that of trees on the moderately well drained soil. This difference in ring SG is due to smaller latewood percentages for trees growing on the poorly drained soil (Fig. 5). The probable reason trees on the poorly drained soil produce less latewood is because more moisture is available in the late spring and early summer on the poorly drained soils. Thus, trees convert to latewood

Table 3. Split-plot analysis of variance shoving effects of soil, site-preparation, and spacing on dbh, specific gravity of whole core, juvenile and mature wood, latewood content of mature wood, juvenile wood core diameter and proportim of the basal area in juvenile vood for slash pine at age 30.

			F-values type III					
Source	DF	Dbh	Whole core SG	Juvenile wood SG	Mature wood SG	Mature wood latewood	Juvenile wood core diameter	Proportion or BA in juvenile wood
Soil	2							
Spacing	3	60.98**	15.88"	3.45	8.60	0.07	11.53**	16.02**
Block (spacing)								
Soil* spacing	2	0.32	2.60	0.37	3.08	0.25	0.42	0.14
Soil* black (spacing)	3							
Site-preparation	3							
Spacing* site-prep	6	5.33**	1.52 1.02	0.95 1.02	0.81 1.21	0.29 1.14	48.71** 2.98	28.60** 0.71
Soil* site-prep	3	1.43	0.77	5.56**	1.14	0.56	10.64**	6.08**
Soil* spac* site-prep	6	0.74	0.68	1.52	1.26	1.12	2.24	0.59
Error	18							
Corrected total	47							

bevels of significance: * = 0.05; ** = 0.01

production later in the growing season on poorly drained than on the moderately well drained soil (Zahner 1963). Figure 6 shows that the first eight rings in trees on the moderately well drained soil are larger than those in trees on the poorly drained soil, but the trend is reversed after the 10th ring from pith. Thus, when ring SG was weighted by annual basal area growth, juvenile wood SG was slightly higher for the trees on the moderately well drained soil but mature wood and all wood SG did not vary between soils (Table 4).

Table 4. Average specific gravity of juvenile, mature, and whole core varieties.

Soil	Average specific gravity		
	Juvenile wood	Mature wood	Whole core
Moderately well drained	0.52	0.58	0.56
Poorly drained	.50	.58	.56

Analysis of variance (Table 3) shows that whole-core SG varied significantly with spacing but that juvenile wood SG and mature wood SG did not (Table 5). The percentage of latewood in mature wood latewood did not vary significantly with spacing, and there was no significant interaction between soil and spacing effects on specific gravity or latewood percent (Table 3).

Mechanical site preparation treatment did not affect SG of whole cores, juvenile wood, or mature wood, or percentage of latewood in mature wood (Tables 3 and 6). There was no significant interaction between spacing and site-preparation for SG or latewood content. There was, however, a significant interaction between soil and site-preparation treatments for juvenile wood SG (Table 3). Juvenile wood SG on moderately well and poorly drained

Table 5. Average whole-core, juvenile-wood, and mature-wood SG and **latewood** content of mature wood by spacing for slash pine at age 30.

Spacing (ft)		
6 x 6	6 x 12	12 x 12
	Whole-core SG	
0.55 a[1]	0.56 ab	0.57 b
	Juvenile-wood SG	
0.51 a	0.51 a	0.51 a
	Mature-wood SG	
0.56 a	0.59 a	0.59 a
	Latewood content of mature wood (percent)	
52 a	54 a	53 a

[1] Values with the same letter do not differ at the 0.5 level according to Tukey's Studentized Range Test.

Table 6. Average whole-core, juveuile-wood, and mature-wood **SG** and **latewood** content of mature wood by mechanical site-preparation **treat**ment for slash pine at age 30.

Mechanical site-preparation treatment			
Control	Scalp	Bed	Harrow
	Whole-core SG		
.56 a	.57 a	.56 a	.56 a
	Juvenile-wood SG		
.51 a	.51 a	.52 a	.51 a
	Mature-wood SG		
.58 a	.59 a	.57 a	.58 a
	Latewood content of mature wood (percent)		
52 a	53 a	53 a	53 a

[1] Values with the same letter do not differ at the 0.5 level according to Tukey's Studentized Range Test.

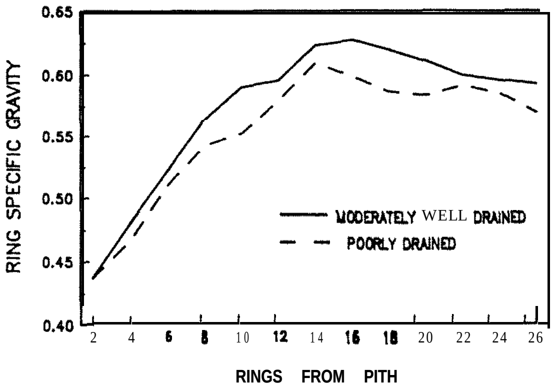

Figure 4. Effect of soil type on ring specific gravity.

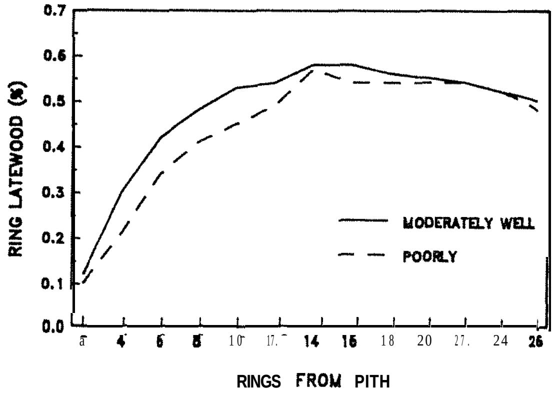

Figure 5. Effect of soil type on proportion of annual ring in latewood.

control and scalped subplots and on poorly drained bedded and harrowed subplots averaged 0.50 to 0.51, compared with 0.53 for bedded and harrowed subplots on the moderately well drained soil.

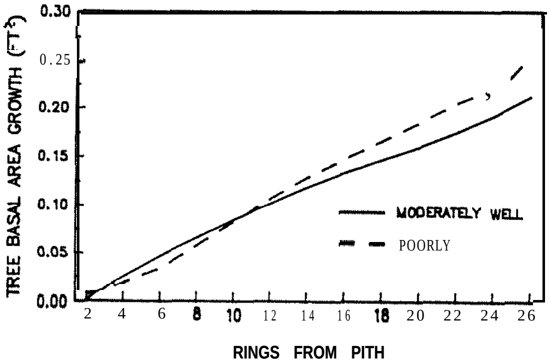

Figure 6. Comparison of average cumulative tree basal area growth for slash pine at age 30 growing on a moderately well drained and poorly drained soil.

The diameter of the juvenile wood core increased significantly with spacing and intensity of site preparation (Tables 3 and 7). Trees planted at wider spacings and on intensively prepared subplots produced large diameters because of increased radial growth during juvenile period. There was also a significant interaction in diameter of the juvenile core between soil type and site preparation treatment (Tables 3 and 7). Average diameter of the juvenile cores of trees on bedded and harrowed subplots on the moderately well drained soil was significantly larger than that of trees receiving the same site preparation treatments on the poorly drained soil. On the poorly drained soil, only trees on harrowed sites had significantly larger juvenile cores than trees on control or other site-preparation treatments (Table 7).

Even though the diameter of the juvenile core was significantly larger in trees planted at wider spacing on intensively site-prepared subplots, the proportion of tree basal area in juvenile wood at age 30 was significantly less in these trees than in trees planted at close spacings on control and scalped plots (Tables 3 and 8). This is because trees planted at the wider spacings had less competition and put on more radial growth after converting to mature wood.

For proportion of tree basal area in juvenile wood, there was a significant interaction between soil type and site-preparation treatment (Tables 3 and 8). Trees on the moderately well drained bedded and harrowed subplots contained significantly more basal area in juvenile wood at age 30 than the trees on the poorly drained soil. For all spacing and site-preparation treatments, trees on the poorly drained soil contained a smaller proportion of their basal area in juvenile wood because they grew more slowly during the juvenile period than during the mature period (Fig. 7).

Table 7. Effect of spacing and site-preparation on diameter of the juvenile wood core for 30-year-old slash pines on moderately well drained and poorly drained soil.

Spacing	Site-preparation treatment			
	Control	Scalp	Bed	Harrow
-- ft --	---------- inch ----------			
	Moderately well-drained soil			
6 x 6	3.0	3.0	3.6	3.7
6 x 12	3.4	3.5	3.9	4.6
12 x 12	3.0	3.0	4.2	4.8
	Poorly-drained soil			
6 x 6	2.9	2.9	3.1	3.2
6 x 12	2.9	3.0	3.3	3.5
12 x 12	3.0	3.3	3.3	3.7

Table 8. Effect of spacing and site-preparation on proportion of tree-basal area in juvenile wood for SO-year-old slash pine on a moderately well drained and poorly drained soil.

Spacing	Site-preparation treatment			
	Control	Scalp	Bed	Harrow
-- ft --	--------- percent ---------			
	Moderately well-drained soil			
6 x 6	30	27	41	40
6 x 12	26	27	36	43
12 x 12	20	19	33	34
	Poorly-drained soil			
6 x 6	25	24	30	32
6 x 12	21	22	26	29
12 x 12	17	20	21	19

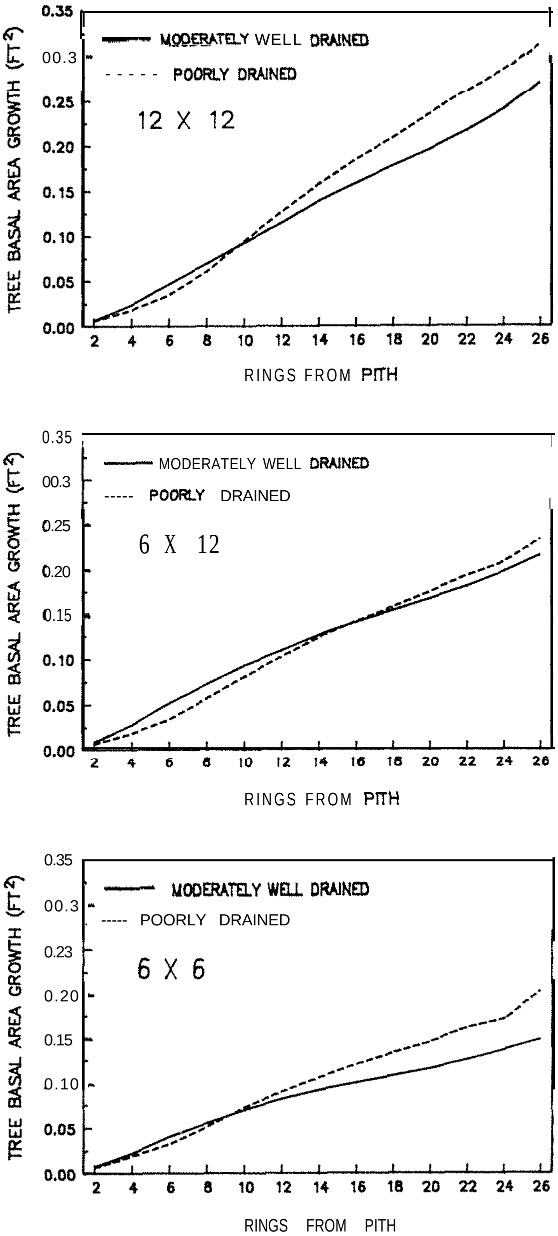

Figure 7. Comparison of average **cumulative** tree basal area growth for slash pine at age 30 planted at three spacings on a moderately well and poorly drained soil.

Conclusions

Planting densities ranging from 6 x 6 ft to 12 x 12 ft on a moderately well drained Orsino soil and a poorly drained Mascote soil did not significantly affect the age of transition from juvenile to mature wood of slash pine on the Coastal Plain of Georgia. Intensive site-preparation increased the duration of juvenility by 2 years on the moderately well drained soil but not on the poorly drained soil. Trees planted on moderately well drained bedded and harrowed subplots produced juvenile wood for 10 rings. Trees on poorly drained bedded and harrowed plots produced juvenile wood for eight rings. Trees planted on control and scalped subplots on both soils produced juvenile wood for only eight rings.

At age 30, SG of all wood, juvenile wood, and mature wood at breast height did not vary significantly by site-preparation treatment or between 6 x 6- and 6 x 12-ft spacings. The SG of all wood of the trees planted 12 x 12 ft was significantly higher than that of the trees planted 6 x 6 ft.

The diameter of the juvenile wood core generally increased with spacing because of early rapid radial growth of trees planted at wider spacings. However, the proportion of tree basal area in juvenile wood was significantly less for trees planted at wider spacings on subplots which received the more intensive site-preparation treatments because these trees grew more rapidly after converting to mature wood than trees planted at close spacings on the control or scalped subplots. Trees on the poorly drained soil contained a smaller proportion of their basal area in juvenile wood at breast height because they grew more slowly during the juvenile period than during the mature period.

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EFFECT OF PRUNING, SPACING, AND THINNING ON JUVENILE WOOD FORMATION IN LOBLOLLY PINE [1]

Mark D. Gibson and Terry R. Clason [2]

Abstract. The age and ring number of juvenile (JW) to mature wood (MW) transition, the JW core diameter, and the proportion of stem cross-sectional area composed of JW were studied in a 39-year-old plantation. The ring number and age of transition from JW to MW were not significantly affected by spacing (planting density), thinning, or pruning. Spacing affected JW core diameters more in butt logs than second logs. JW core diameters in trees pruned in two-stages were not affected by thinning. Thinning appeared to influence the proportion of JW in the lower end of the butt log in trees pruned in two stages. Pruning applied as a one-stage, compared with a two-stage, process did not appear to significantly alter the JW core diameter or the proportion of JW.

Introduction

Approximately one-third of the South's commercial pine timberland is classified as plantations. Each year less and less of our raw material comes from older natural stands of timber. Soon the majority of the wood supply entering our forest product manufacturing processes will come from plantations. By the year 2000, plantations are projected to contain 48 percent of the pine softwood volume, and by the year 2030 as much as 73 percent (USDA Forest Service 1988, Brown and McWilliams 1990). Although wood from plantation grown trees will be more uniform in quality, this raw material will be younger, smaller, and generally lower in quality. The increased amount of knots and juvenile wood (JW) with its lower specific gravity, shorter tracheids, larger microfibril angles, thinner cell walls, lower percentage of latewood, greater longitudinal shrinkage, and lower strength, could have a severe economic impact (Bendtsen 1978, Thomas 1984, Megraw 1985, Cubbage 1990, Thomas and Kellison 1990, Saucier 1990). The concern over the increased proportion of JW compared to mature wood (MW) entering wood product manufacturing processes spurred several investigations with the objective of characterizing the amount of JW in plantation grown southern pine. Zobel and Blair (1976) defined JW as wood surrounding the pith of the tree having a "lifeless" appearance, low light reflectivity, "cheesy" consistency, low proportion of latewood, and a high proportion of reaction wood. Hence, a visual estimation of the transition from JW to MW is possible, though not extremely accurate. Many investigators intially attempted to deliniate a boundary

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between JW and MW at a specific growth ring. Zobel and Blair (1976) indicated that there was no sharp dividing line between JW and MW because one gradually grades into the other. They also found that loblolly pine (*Pinus taeda* L.) generally produced JW for 7-11 years. Megraw (1985) found *loblolly* pine generally produced JW up to about year 10 from the pith. Clark and Saucier (1987) looked at initial planting density (spacing) and its effect on JW formation. They found that the age of transition from JW to MW in loblolly pine was not affected by planting density, that loblolly produced JW from the pith to ring 14, and that it began MW production at ring 16 from the pith in all spacings sampled. They also found that the proportion of JW in the stem at breast height was not significantly influenced by planting density; however, slash pine (*Pinus elliottii* Engelm. var. *elliottii*) was significantly affected.

Saucier (1990), commenting on a 30-year-old loblolly pine spacing study, said that close spacings did restrict JW core diameters, but without thinning the proportional area in JW was only slightly less than that of trees planted at wider spacings. Be also noted that growth of individual trees at the close spacings was significantly reduced. The greatest impact of plantation wood will be in the solid wood products, although other processes and products will be affected to some degree (Senft et al., 1985; Oberg 1990). One silvicultural practice which may aid in increasing the quality of this wood is pruning. Investigations into the effect of pruning on tree growth and wood production have shown definite benefits are associated with this silvicultural practice. Specifically, pruning is the only way to ensure the production of significant volumes of clear wood in intensively managed stands (Cahill et al., 1986). Briggs and Smith (1986) summarizing the effect of pruning into the active crown on wood properties indicated this practice should accelerate the transition from JW to MW, thereby reducing the size of the JW core and the proportion of JW in the stem. If pruning can be applied economically, significantly reduce the size of the JW core, and increase the grade recovery from plantation timber, more emphasis could be placed upon this technique. However, more information on pine plantations in north Louisiana and the South is needed, especially as it relates to the effect of pruning on lumber grade, JW core size, and other measures of wood quality. This study was a preliminary investigation to ascertain whether pruning, spacing, and thinning in plantation loblolly pine affects the age and ring number of transition from JW to MW, the diameter of the JW core, and the proportion of stem cross-sectional area composed of JW. Further sampling of the plantation was dependent upon the results of this study.

Materials And Methods

The plantation was established in February 1950 on an abandoned cotton field at the Hill Farm Research Station, in Homer, LA. Initial planting was done with l-year-old loblolly pine seedlings at each of the following spacings: 4 x 4, 6 x 6, 6 x 8, 8 x 8, and 10 x 10 ft. The spacings were randomly assigned to ten 1-ac blocks so that each spacing was replicated twice. In 1955, at age 6, four treatments were applied to each of four 0.25-ac plots within the ten l-ac blocks: (1) thinned to 400 trees/ac (TPA); (2) pruned to 8 ft, or up to ½ total height; (3) thinned and pruned;

and (4) control. In 1960, at age 11, the three culturally treated plots within each block were randomly thinned to 100, 200, and 300 TPA, and all trees, except the controls, were pruned to 17 ft. In 1978, at age 29, the plots thinned at age 11 were thinned again.

Sample trees were selected and felled in November 1988. Stems were bucked so that disks, each about 1-2 inches thick, were removed at the base and top of each of the first two logs. Consequently, disks were removed at the following positions along the stem: 0-0.7 ft; 17-17.7 ft; and 34-34.7 ft. The actual location of each sample disk may have deviated slightly on a case-by-case basis to prevent defects such as knots (branches), fusiform cankers, etc., from altering growth ring patterns. The actual distance from the base of the tree to the center of each disk was measured and recorded. Log length averaged 16.3 ft after disk removal. Average tree and log diameters are presented in Table 1.

Disks were transported to the laboratory, dried in a forced-air oven, then sanded using a belt sander and progressively finer-grit sandpaper until a smooth, clean surface resulted. The diameter outside bark (DOB) of each disk was measured using a steel diameter tape. This average diameter was located on the sanded surface of each disk and a pencil line scribed from bark-to-bark through the pith. Every effort was made to locate this line so that the bark-to-pith distance (radius) was equal on either side of the pith. However, when equal radii were not possible, the diameter line was located so that radii were as nearly equal as possible. Individual growth rings were numbered from the bark inward to the pith on each radius beginning with ring 39. The outside of each latewood (LW) segment was clearly marked for easier measurement and to avoid problems arising from false or discontinuous growth rings. Actual measurements of earlywood (EW) and LW widths within each growth ring were made to the nearest 0.001-inch using a pair of digital calipers. A Bausch and Lomb StereoZoom™ microscope and incident light source allowed more accurate placement of the calipers for each measurement. Distances along each radius (sides A and B) from the pith to the outside edge of each EW and LW segment were recorded. Consequently, the radius from the pith to the outer boundary of any growth ring could be calculated and, hence, the diameter of a core of wood encompassed by that growth ring could be determined.

The transition between JW and MW was located visually by both ring number from the pith and tree age. JW was characterized as wood near the center of the tree with a more rapid growth rate, lower percentage of latewood (LW%) within the growth ring, and lower light reflectivity from the surface. Since the LW% ranged between 35 and 50 percent on the average when the visual transition occurred, we used LW% as a general guideline for identifying the outer boundary of the JW. JW core diameters were calculated by summing the distance from the pith to the outer edge of this visually located boundary along radius A and B.

The average diameter inside bark (DIB) of each disk was used in the formula, Area = $(DIB)^2 \times 0.005454$, to calculate its cross-sectional area. The average visual JW core diameter was also substituted in the formula to calculate the cross-sectional area of the visual JW core. The proportion of JW in the disk was determined by dividing the cross-sectional area of the JW by the disk cross-sectional area and expressing that value as a percentage.

Table 1. Average dbh of sample trees and scaling dib of logs grouped by treatment at age 6 and classified within groups by number of trees/ac at age 11.[1]

TPA or spacing	Dbh Av	Dbh Range	DIB log 1 (top) Av	DIB log 1 (top) Range	DIB log 2 (top) Av	DIB log 2 (top) Range
			(inch)			
			T1P			
100	17.7	15.7-19.4	13.8	11.7-15.0	12.7	11.0-13.6
200	14.5	12.0-16.6	12.2	10.1-13.9	10.7	8.6-11.8
300	13.5	12.0-14.8	11.4	10.7-12.5	10.0	9.0-11.4
Av	15.2	12.0-19.4	12.5	10.1-15.0	11.1	8.6-13.6
			T2P			
100	17.3	16.5-18.4	13.5	13.0-14.2	12.1	11.5-13.2
200	14.6	14.1-15.1	12.3	11.6-12.7	10.9	10.0-11.4
300	14.9	13.0-17.8	12.9	11.3-14.9	11.2	9.7-13.0
Av	15.6	13.0-18.4	12.9	11.3-14.9	11.4	9.7-13.2
			UT2P			
100	16.4	13.7-19.6	13.3	10.9-16.5	11.8	9.4-15.0
200	15.5	14.4-16.5	12.2	10.6-13.2	10.8	9.7-11.8
300	15.2	14.3-16.1	12.7	11.8-13.7	11.7	10.5-12.5
Av	15.7	13.7-19.6	12.8	10.6-16.5	11.4	9.4-15.0
			Control			
4 x 4	11.2	10.7-12.0	9.2	8.8- 9.7	8.1	7.8- 8.6
6 x 6	12.7	10.7-15.0	10.3	8.6-12.6	9.5	7.9-11.5
6 x 8	11.6	10.9-12.4	9.5	9.0-10.0	8.4	7.9- 8.9
8 x 8	12.1	10.4-14.2	9.9	8.5-11.7	9.0	7.7-10.6
10 x 10	15.7	12.3-17.5	12.9	10.5-14.5	11.6	8.9-13.2
Av	12.7	10.4-17.5	10.4	8.5-14.5	9.3	7.7-13.2

[1] Abbreviations correspond to: Dbh- diameter at breast height; DIB- diameter inside bark; TPA- trees/ac; Av- average; T1P- plots which were pruned once and thinned; T2P- plots pruned twice and thinnned; UT2P- plots pruned twice and unthinned at age 6; Control- plots unthinned and unpruned.

The age 29 treatments did not affect the age or ring number from the pith at which transition from JW to MW occurred or the diameter of the JW core since transition occurred prior to that time in all disks. However, these treatments did influence the proportion of stem cross-sectional area composed of JW, since the sample trees were not harvested until 1988 at age 39.

Although the statistical design began as a randomized complete block, treatments applied at age 29 confounded the original design and made separation of treatment effects difficult. Consequently, two-sample t-tests and one-way analyses of variance based on a completely random design were used to compare the treatment means.

All two-sample t-tests included a test for equality of variance, the F statistic (Steel and Torie 1980). This test was useful for deciding the legitimacy of pooling variances in testing the hypothesis of equality of population means for samples with unpaired observations. Only if the variances were found to be equal was it legitimate to pool variances. Otherwise, the comparison was determined on the basis of unpaired observations and unequal variances, and the critical t-value was determined with the "effective degrees-of-freedom" computed according to Satterthwaite's approximation (Satterthwaite 1946, Steel and Torrie 1980). That procedure gave the best comparison possible and assured that significant results were not attributable to differences in variance, but to differences between the means. Trees were placed into four groups according to treatment at age 6: thinned; thinned and pruned; unthinned and pruned; and control. The application of the age 11 thinning and pruning treatments to the first three of these groups resulted in 9 plots which were pruned once [thinned plots (T1P)] , 18 plots which were pruned twice [unthinned at age 6 and pruned plots (UT2P), and thinned and pruned plots (T2P)], and 9 control plots (unthinned and unpruned).

Results And Discussion

Age of Transition from Juvenile to Mature Wood

Since the major emphasis of this project was the affect of spacing, thinning, and pruning on sawtimber quality, only the first three disks in each tree were considered in the analyses. In addition, the visually determined age of transition from JW to MW occurred prior to age 29 in the first three disks in all trees. Therefore, the transition in the butt and second logs was not affected by the age 29 treatments.

A visual estimation was used to locate the transition from JW to MW because of the preliminary nature of this study and as a time conserving measure. Wood product manufacturing processes are also more likely to employ a visual estimation of the extent of JW in the stem.

Effect of planting density (spacing). Control treatments were compared at each disk level. Controls consisted of plots planted at 4 x 4, 6 x 6, 6 x 8, 8 x 8, and 10 x 10-ft spacings with no further silvicultural treatment. A one-way analysis of variance comparing these control treatments indicated no statistical difference in the ring number or the age at which the transition from JW to MW occurred. The average age of transition (Table 2) was 12, 16, and 22, and the average number of growth rings in the JW core was 12, 10, and 12 in disks 1, 2, and 3, respectively. Hence, planting density alone did not affect the JW to MW transition in loblolly pine on this site. Since none of the thinned and pruned plots sampled were planted at the 10x10 spacing, this treatment was dropped from the analysis and a further comparison of the 4 x 4, 6 x 6, 6 x 8, and 8 x 8 spacings was made by disk using a one-way analysis of variance. No significant difference was found either in ring number or age at which the transition from JW to MW occurred among these spacings for disk 1, 2, or 3 (Table 2). Therefore, these four spacings were pooled to form a control treatment mean (C).

Table 2. Effect of planting density on ring number and age at which the transition from JW to MW occurred.

	Disk	Planting density 4 x 4	6 x 6	6 x 8	8 x 8	10 x 10
Ring number	1	11 A[1]	12 A	12 A	12 A	12 A
	2	10 A	10 A	10 A	9 A	10 A
	3	12 A	13 A	12 A	13 A	12 A
Age (yr)	1	11 A	12 A	13 A	12 A	12 A
	2	17 A	16 A	17 A	16 A	16 A
	3	22 A	23 A	22 A	23 A	21 A
Ring number	1	11 A	12 A	12 A	12 A	
	2	10 A	10 A	10 A	9 A	
	3	12 A	13 A	12 A	13 A	
Age (yr)	1	11 A	12 A	13 A	12 A	
	2	17 A	16 A	17 A	16 A	
	3	22 A	23 A	22 A	23 A	

[1] Values in the same row followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

Table 3. Effect of age 11 thinning and pruning treatments on ring number and age at which the transition from JW to MW occurred.

	Disk	T1P[1] 100	200	300	T2P 100	200	300	UT2P 100	200	300
Ring number	1	12A[2]	15A	12A	14A	13A	13A	12A	13A	13A
	2	12A	13A	10A	13A	13A	11A	11A	13A	10A
	3	14A	14A	13A	14A	13A	11A	14A	14A	12A
Age (yr)	1	12A	15A	12A	14A	13A	14A	13A	14A	13A
	2	18A	20A	16A	19A	19A	17A	17A	19A	17A
	3	24A	24A	23A	24A	23A	21A	24A	24A	22A

[1] Treatments correspond to: T1P- thinned and once-pruned; T2P- thinned and twice-pruned; and UT2P- unthinned at age 6 and twice-pruned; 100, 200, and 300 refer to TPA remaining following the age 11 thinning.

[2] Values in the same row under each major treatment group followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

Effect of age 11 thinning treatments. Initially, the thinning treatments applied at age 11 were compared by disk using a one-way analysis of variance. There was no statistical difference at the T-percent level of probability in either the ring number or the age at which the transition from JW to MW occurred among plots thinned to 100, 200, and 300 TPA at each disk level for the T1P, T2P, or UT2P groupings (Table 3). In other words, the thinning treatments at age 11 did not affect the JW to MW transition. Hence, the 100, 200, and 300 TPA thinning treatments were pooled to create the three separate groupings of T1P, T2P, and UT2P. These groupings, based on treatment at age 6, allowed comparisons similar to those used by Valenti and Cao (1986) to be applied to the data.

Effect of thinning and pruning. A one-way analysis of variance was used to compare the four groups: T1P, T2P, UT2P, and C. The GLM (General Linear Models) procedure was used since the control treatment had a larger number of observations than the other treatments. The GLM procedure is preferred with an analysis of variance on unbalanced data (SAS Institute 1985). The results indicated that no statistical difference existed among the four treatment means for either the ring number or the age at which the transition from JW to MW occurred for disks 1, 2, or 3 (Table 4). In other words, the pruning and thinning treatments did not appear to affect the ring number or age at which the transition from JW to MW occurred in the butt or second log of loblolly pine on this site.

Summary. The transition from JW to MW did not appear to be affected by spacing, thinning, or pruning. This conclusion is supported by the work of Clark and Saucier (1989). They discovered that planting density had no significant affect on the age (ring number) of transition in loblolly pine planted in the Piedmont of South Carolina at 6 x 6, 8 x 8, 10 x 10, and 12 x 12 ft spacings. These trees produced JW through 14 rings from the pith and began producing MW by ring 16 in all spacings. Planting density did have a significant affect on the diameter of the juvenile wood core, however. Clark et al. (1989) examined loblolly pine planted on three separate geographic locations (Georgia--Atlantic Coastal Plain, Georgia--Piedmont, and Arkansas--Upper Coastal Plain) on a 6x6 spacing and thinned to 70 ft^2 of basal area/ac at age 15. They found, under these conditions, that loblolly pine appeared to produce JW for the first 10 to 12 rings and began to produce MW about 14 to 16 rings from the pith. Comparatively, our trees produced JW through ring 12, 10, and 12 in disks 1, 2, and 3, respectively.

Diameter of The Juvenile Wood Core

Effect of planting density (spacing). The effect of planting densities on the diameter of the JW core was compared at each disk level using a one-way analysis of variance. The lower end of the butt log (disk 1) was the only position significantly affected by planting density. A comparison of the means (Table 5) using Tukey's procedure (Steel and Torrie 1980, SAS Institute 1985) showed that at the lower end of the butt log only the 4 x 4 and 10 x 10-ft spacings produced significantly different core diameters. The 10 x 10-ft spacing yielded the larger diameter. Different planting densities did not produce significantly different JW core diameters at the disk 2 and 3 levels.

Table 4. Effect of age 6 treatments on ring number and age at which the transition from JW to MW occurred.

	Disk	T1P[1]	T2P	UT2P	Control
Ring number	1	13 A[2]	13 A	13 A	12 A
	2	12 A	12 A	11 A	10 A
	3	14 A	13 A	14 A	12 A
Age (yr)	1	13 A	14 A	13 A	12 A
	2	18 A	18 A	18 A	16 A
	3	24 A	22 A	24 A	23 A

[1] Treatments correspond to: T1P- thinned and once-pruned; T2P- thinned and twice-pruned; UT2P- unthinned at age 6 and twice-pruned; and control- no thinning or pruning.

[2] Values in the same row followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

Table 5. Effect of planting density on JW core diameter.

	Planting density				
Disk	4 x 4	6 x 6	6 x 8	8 x 8	10 x 10
	(inch)				
1	4.5 B[1]	7.1 AB	7.0 AB	6.5 AB	9.2 A
2	4.9 A	5.7 A	6.3 A	5.5 A	7.8 A
3	5.0 A	5.9 A	5.8 A	5.8 A	6.9 A
1	4.5 B	7.1 A	7.0 A	6.5 AB	
2	4.9 A	5.7 A	6.3 A	5.5 A	
3	5.0 A	5.9 A	5.8 A	5.8 A	

[1] Values in the same row followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

When JW core diameters were compared among planting densi ties, it was apparent that the butt log was more affected than the second log. When planting densities were ranked according to mean core diameter, no consistent pattern of changing core diameter with changing planting density was evident. This relationship differs from that found by Clark and Saucier (1989). They found that slash pine JW core diameters at breast height were significantly affected by planting density, but the relationship for loblolly pine was less clear. However, both slash and loblolly pine breast height core diameters did increase with an increase in spacing.

Since none of the thinned and pruned plots were planted at the 10 x 10 spacing, this treatment was dropped from later analyses. An one-way analysis of variance comparing the 4 x 4, 6 x 6, 6 x 8, and 8 x 8 spacings was performed. The results indicated that in disk 1 there was a significant effect on JW core diameter due to planting density. In disks 2 and 3, however, no significant effect was noticeable. A comparison of the means using Tukey's procedure is presented in Table 5 and indicates that the 4 x 4-ft spacing produced a significantly smaller JW core than either the 6 x 6 and 6 x 8-ft spacings. Again, no consistent trend of increased JW core diameter with increased spacing was noticeable.

Effect of age 11 thinning treatments. The thinning treatments applied at age 11 were compared by disk for each of the T1P, T2P, and UT2P treatments. There was no statistical difference at the 5-percent level of probability in the diameter of the JW core among plots thinned to 100, 200, or 300 TPA at any disk level, with the exception of disk 3 of the T2P treatment (Table 6). Here the 100 TPA treatment produced a significantly larger core than the 300 TPA treatment, but neither differed significantly from the 200 TPA treatment.

Effect of thinning and pruning [Twice-pruned trees (thinned and pruned vs. pruned)]. Table 7 presents the results of two-sample t-tests used to compare UT2P trees with T2P trees. This comparison indicated no statistical difference in the diameter of the JW core at the 5-percent level of probability for disks 1 and 2. Because age 11 thinning treatments had a significant effect on core diameter in disk 3, the UT2P and T2P trees were compared for each level of thinning separately. Results indicate no

Table 6. Effect of age 11 thinning and pruning treatments on JW core diameter.

Disk	T1P[1] 100	T1P 200	T1P 300	T2P 100	T2P 200	T2P 300	UT2P 100	UT2P 200	UT2P 300
	(inch)								
1	9.2A[2]	9.0A	6.7A	9.6A	8.2A	8.8A	7.8A	7.4A	7.0A
2	8.9A	8.0A	6.2A	8.7A	7.7A	7.0A	7.2A	7.3A	6.3A
3	9.0A	7.6A	6.1A	8.3A	7.0AB	6.1B	7.7A	7.5A	6.7A

[1] Treatment acronyms are listed in footnote 1 of Table 3.

[2] Values in the same row under each major treatment group followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

Table 7. Results of two-sample t-tests used to compare JW core diameters for twice- and once-pruned treatments.

Comparison[1]					
Sample 1	Sample 2	Disk	S1	S2	T-test
			-(inch)-		
UT2P	T2P	1	7.4	8.9	MS
		2	6.9	7.8	NS
(100)	(100)	3	7.7	8.3	NS
(200)	(200)	3	7.5	7.0	NS
(300)	(300)	3	6.7	6.1	NS
2P	T1P	1	8.1	8.3	NS
		2	7.4	7.7	NS
(100)	(100)	3	8.0	9.0	NS
(200)	(200)	3	7.3	7.6	NS
(300)	(300)	3	6.4	6.1	NS

[1] Abbreviations correspond to: S1- sample 1 mean; S2- sample 2 mean; T-test- result of two-sample t-test; * = significant at the 5-percent level of probability; NS- not significantly different; T1P- thinned and once-pruned; T2P- thinned and twice-pruned; UT2P- unthinned at age 6 and twice-pruned; 2P- twice-pruned = pooling of UT2P & T2P; 100- thinned to 100 TPA at age 11; 200- thinned to 200 TPA at age 11; 300- thinned to 300 TPA at age 11.

statistical difference in core diameter between UT2P and T2P trees at any level of thinning. Consequently, the data was combined (pooled) to create a twice-pruned (2P) data set which was compared with the T1P data set (Table 7).

Twice-pruned vs once-pruned. The JW core diameters were not significantly different among twice-pruned and once-pruned trees in disks 1 and 2. The comparison for disk 3 was applied to each age 11 thinning level separately, since these thinnings had a significant effect on core diameter. Results indicated no statistical difference in core diameters for 2P and T1P trees at any level of thinning (Table 7).

Comparison of thinned and pruned plots to control plots. Table 8 presents the results of two-sample t-tests comparing UT2P, T2P, and T1P treatments with their corresponding control treatments. Comparisons of the UT2P trees for each age 11 thinning treatment with their matched control treatments indicated pruning and thinning do not appear to influence the diameter of the JW core except for the 200 TPA thinning in disk 3. In this case, the UT2P trees have a larger JW core diameter than the control. T2P trees compared with their matched controls indicated that the core diameters of the thinned and twice-pruned trees were significantly larger than those of the controls at the 100 TPA level for all disks, at the 200 TPA level at a 4 x 4-ft spacing, but not at the 6 x 8-ft spacing for disk 1 only, and at the 300 TPA level for disk 2. The T1P trees were significantly affected only at the 100 TPA level in all disks. In this case, the thinned and once-pruned trees had larger core diameters than the controls.

Summary. Pruning treatments appeared to have little or no significant affect on the diameter of the JW core except when trees were initially thinned at age 6. A possible explanation for this behavior is that the initial thinning to 400 TPA at age 6 in combination with the subsequent thinnings at age 11 increased tree growth during the period of juvenility and thereby increased the JW core size. Clark and Saucier (1989) point to this same response and suggest that planting density can influence the size of the JW core by controlling radial growth. They suggest that a close spacing of 8 x 8 ft and subsequent thinning after the trees are producing MW at the 1 or 1½ log height level can reduce the JW core size. Our results appear to reinforce their conclusion.

Proportion of Disk Cross-Sectional Area in Juvenile Wood

Although the transition from JW to MW occurred prior to age 29 in the first three disks in all trees, the proportion of JW in each disk depends on the diameter of the disk at age 39, when the trees were harvested. Therefore, the proportion of JW may have been affected by the age 29 thinning treatments. The random overlaying of these thinning treatments on the age 11 thinning and pruning treatments made separation of individual treatment effects difficult or impossible. Therefore, conclusions regarding the affect of thinning and pruning on JW proportion are made with caution. For consistency of comparison, the statistical analyses were performed on the age 6 grouping.

Effect of planting density (spacing). The effect of planting densities on the proportion of disk cross-sectional area in JW was compared at each disk level using a one-way analysis of variance. Disk 1 exhibited a significant difference in the proportion of disk cross-sectional area in JWamong spacings. No statistical difference in the proportion of JW was apparent in disk 2 and 3 (Table 9).

After dropping the 10 x 10 ft spacing from the analysis, disk 1 again exhibited significant differences in the proportion of JW produced by trees at different planting densities (Table 9). No statistical difference in the JW proportion was found for disks 2 and 3.

Table 8. Results of two-sample t-tests used to compare JW core diameters for twice-pruned treatments with their control treatments, and once-pruned treatments with their control treatments.

Comparison[1] Sample 1	Sample 2	Disk	S1	S2	T-test
			-(inch)-		
C	C				
T11 (6 x 8)	T13 (8 x 8)	1	7.1	6.5	NS
		2	5.7	5.5	NS
		3	5.9	5.8	NS
T10 (4 x 4)	T12 (6 x 8)	1	4.5	7.0	*
		2	4.9	6.3	NS
		3	5.0	5.8	NS
UT2P	C				
T4 (100)	T13 (8 x 8)	1	7.8	6.5	NS
		2	7.2	5.5	NS
		3	7.7	5.8	NS
T5 (200)	T12 (6 x 8)	1	7.4	7.0	NS
		2	7.3	6.3	NS
		3	7.5	5.8	*
T6 (300)	T10 (4 x 4)	1	7.0	4.5	NS
		2	6.3	4.9	NS
		3	6.7	5.0	NS
T2P	C				
T7 (100)	T11 & 13 (6 x 6, 8 x 8)	1	9.6	6.8	*
		2	8.7	5.6	*
		3	a.3	5.9	*
T8 (200)	T10 & 12 (4 x 4, 6 x 8)	1	-	-	
		2	7.7	5.6	NS
		3	7.0	5.4	NS
T8 (200)	T10 (4 x 4)	1	8.2	4.5	*
		2	-	-	
		3	-	-	
T8 (200)	T12 (6 x 8)	1	8.2	7.0	NS
		2	-	-	
		3	-		
T9 (300)	Tll & 13 (6 x 6, 8 x 8)	1	8.8	6.8	NS
		2	7.0	5.6	*
		3	6.1	5.9	NS
T1P	C				
T1 (100)	Tll (6 x 6)	1	9.2	7.1	*
		2	8.9	5.7	*
		3	9.0	5.9	*
T2 (200)	T10 (4 x 4)	1	9.0	4.5	NS
		2	8.0	4.9	NS
		3	7.6	5.0	NS
T3 (300)	T11 (6 x 6)	1	6.7	7.1	NS
		2	6.2	5.7	NS
		3	6.1	5.9	NS

[1] Abbreviations correspond to: S1- sample 1 mean; S2- sample 2 mean; T-test- result of two-sample t-test; T1, etc.- treatment 1 = T1P, 100 TPA, etc.; * = significant at the 5-percent level of probability; NS- not significantly different: - = nonvalid comparison; T1P- thinned and once-pruned; T2P- thinned and twice-pruned; UT2P- unthinned at age 6 and twice-pruned: C- no pruning or thinning: 100- thinned to 100 TPA at age 11; 200- thinned to 200 TPA at age 11; 300- thinned to 300 TPA at age 11; 6 x 6- 6 x 6-ft planting density.

Table 9. Effect of planting density on the proportion of JW.

Disk	Planting density				
	4 x 4	6 x 6	6 x 8	8 x 8	10 x 10
	------------ (percent) --------- ----				
1	16.8B[1]	29.88	34.9A	28.6AB	35.1A
2	31.5A	32.58	48.0A	31.9A	43.1.A
3	42.38	44.48	50.7A	46.6A	48.0A
1	16.8B	29.8AB	34.9A	28.6AB	
2	31.5A	32.5A	48.0A	31.9A	
3	42.3A	44.46	50.7A	46.68	

[1] Values in the same row followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

When the proportion of disk cross-sectional area in JW was compared among planting densities, it was apparent that the butt log was more affected than the second log. Trends regarding increases or decreases in the proportion of JW with changes in planting density were not apparent.

Effect of age 11 thinning treatments. The thinning treatments applied at age 11 were compared by disk for each of the T1P, T2P, and UT2P treatments. There was no statistical difference at the 5-percent level of probability in the proportion of JW among plots thinned to 100, 200, or 300 TPA at any disk level, with the exception of disk three of the T2P treatment (Table 10). Here, the 300 TPA treatment produced a significantly smaller proportion of JW than the 100 or 200 TPA treatments. This outcome follows logically from the effect of these treatments on JW core diameter mentioned earlier.

Table 10. Effect of age 11 thinning and pruning treatments on the proportion of JW.

Disk	T1P[1]			T2P			UT2P		
	100	200	300	100	200	300	100	200	300
	-------------------- (percent) ------------------------								
1	25.7A[2]	34.7A	24.0A	29.0A	29.0A	29.6A	20.7A	21.8A	19.0A
2	'43.28	47.1A	32.7A	44.88	42.5A	33.2A	32.7A	39.919	28.0A
3	55.2A	51.6A	39.46	48.88	44.78	32.8B	44.86	48.9A	35.88

[1] Treatment acronyms are listed in footnote 1 of Table 3.

[2] Values in the same row under each major treatment group followed by the same capital letter do not differ significantly at the 0.05 level according to Tukey's w procedure.

Effect of thinning and pruning. Twice-pruned trees (thinned and pruned vs. pruned). Table 11 presents the results of two-sample t-tests used to compare UT2P trees with T2P trees. This comparison indicated that disk 1 of the UT2P trees contained a significantly lower proportion of JW than the T2P trees. No statistical difference in the proportion of JW was found at the 5-percent level of probability for disk 2. Because the age 11 thinning treatments had a significant effect on the proportion of JW in disk 3, the UT2P and T2P trees were compared separately for each level of thinning. Results indicated no statistical difference in the proportion of JW between UT2P and T2P trees at any level of thinning for disk 3. Consequently, the data was combined (pooled) to create a twice-pruned (2P) data set which was compared with the TIP data set (Table 11).

Table 11. Results of two-sample t-tests used to compare the proportion of JW for twice- and once-pruned treatments.

Comparison[1]					
Sample 1	Sample 2	Disk	S1	S2	T-test
			-(percent)-		
UT2P	T2P	1	20.5	29.2	*
		2	33.5	40.2	NS
(100)	(100)	3	44.8	48.8	NS
(200)	(200)	3	48.9	44.7	NS
(300)	(300)	3	35.8	32.8	NS
UT2P	T1P	1	20.5	28.2	NS
T2P	TIP	1	29.2	28.2	NS
2P	T1P	2	36.8	41.0	NS
(100)	(100)	3	46.8	55.2	NS
(200)	(200)	3	46.8	51.6	NS
(300)	(300)	3	34.3	39.4	NS

[1] Abbreviations/acronyms are listed in footnote 1, Table 7.

Twice- vs. once-pruned. The JW proportions were not significantly different among twice- and once-pruned trees at any disk or thinning level (Table 11).

Comparison of thinned and pruned plots to control plots. Table 12 presents results of two-sample t-tests comparing UT2P, T2P, and T1P treatments with their corresponding control treatments. Comparisons of the UT2P trees for each age-11 thinning treatment with their matched control treatments indicated pruning and thinning do not appear to influence the proportion of disk cross-sectional area in JW. T2P trees compared with their matched controls indicated that the proportion of JW in the thinned and twice-pruned trees was not significantly different from that of the controls, except at the 200 TPA level for both a 4 x 4- and a 6 x 8-f t spacing in disk 1. At the 4 x 4-ft spacing, the thinned and twice-pruned trees had a significantly larger JW proportion, but at the 6 x 8-f t spacing, had a smaller proportion of JW than the control trees. The T1P trees were significantly affected only at the 100-TPA level in disk 2. In this case, the thinned and once-pruned trees had a larger proportion of JW than the controls.

Summary. In twice-pruned trees, the UT2P treatment produced a significantly lower proportion of JW in the lower portion of the butt log than the

T2P treatment, 20.5 vs 29.2 percent. The proportion of JW in the upper portion of the butt log and the second log was not significantly affected by pruning. The fact that the UT2P trees generally produced smaller proportions of JW than the T2P or T1P trees is logical in view of the JW core size behavior in these treatments. Exactly how much of the difference in JW proportion among twice-pruned trees and among twice-pruned and once-pruned trees is due to pruning and how much is due to thinning is difficult to determine.

Unfortunately, comparisons of thinning and pruning treatments with their matched controls produced some conflicting results. The age 29 thinning treatments are suspected of contributing to the confusion. Based upon the response of JW core size to the thinning and pruning treatments, the expected outcomes were that the UT2P treatment would not significantly alter the JW proportion from that of the controls, the T2P treatment would increase the proportion above that of the controls, and the T1P treatment (especially at the 100-TPA level) would significantly increase the JW proportion. The T2P treatment showed a reversal of the expected outcome, while the UT2P and T1P treatments behaved essentially as expected. The UT2P treatment generally did not change the proportion of JW significantly from that of the control treatment. The T2P treatment appeared to influence the proportion of JW slightly. In all but one case, the T2P trees were either not significantly different from the controls or had a smaller proportion of their cross-sectional area in JW. The reduced JW proportion due to the T2P treatments was the opposite of the expected outcome when the effect of these treatments on JW core size was considered. Since the T2P treatment increased the JW core diameter over that of the controls, we expected a subsequent increase in the proportion of JW, which did not occur. Evidently the thinning treatments at age 29 modified the affect of the T2P treatments. The T1P treatment was only affected by the 100 TPA thinning at age 11 when compared with the control treatment. The proportion of JW actually was greater in the T1P trees than in the control trees. This reversal from the previously mentioned trend is logical when the effect of the treatment on JW core diameter is considered. In this case, an increase in tree growth during the

Table 12. Results of two-sample t-tests used to compare the proportion of JW for twice-pruned treatments with their control treatments, and once-pruned treatments with their control treatments.

Comparison[1] Sample 1	Sample 2	Disk	S1	S2	T-test
			(percent)		
C	C				
T11 (6X8)	T13 (8X8)	1	29.8	28.6	NS
		2			
		3	[illegible]	[illegible]	NS
T10 (4X4)	T12 (6X8)	1	16.8	34.9	*
		2	31.5	48.0	NS
		3	42.3	50.7	NS
UT2P	C				
T4 (100)	T13 (8X8)	1	20.7	28.6	NS
		2	32.7	31.9	NS
		3	44.8	46.6	NS
T5 (200)	T12 (6X8)	1	21.8	34.9	NS
		2	39.9	48.0	NS
		3	48.9	50.7	NS
T6 (300)	T10 (4X4)	1	19.1	16.8	NS
		2	28.0	31.5	NS
		3	35.7	42.3	NS
T2P	C				
T7 (100)	T11 & 13 (6X6, 8X8)	1	29.0	29.2	NS
		2	44.8	32.2	NS
		3	48.8	45.5	NS
T8 (200)	T10 & 12 (4X4, 6X8)	1	-	-	-
		2	42.5	39.7	NS
		3	44.7	46.5	NS
T8 (200)	T10 (4X4)	1	29.1	16.8	*
		2	-	-	-
		3			-
T8 (200)	T12 (6X8)	1	29.1	34.9	*
		2	-	-	-
		3		-	-
T9 (300)	T11 & 13 (6X6, 8X8)	1	29.6	29.2	NS
		2	33.2	32.2	NS
		3	32.8	45.5	NS
T1P	C				
T1 (100)	T11 (6X6)	1	25.7	29.8	NS
		2	43.2	32.5	*
		3	55.2	44.4	NS
T2 (200)	T10 (4X4)	1	34.7	16.8	NS
		2	47.1	31.5	NS
		3	51.6	42.3	NS
T3 (300)	T11 (6X6)	1	24.0	29.8	NS
		2	32.7	32.5	NS
		3	39.4	44.4	NS

[1] Abbreviations/acronyms are listed in footnote 1, Table 8.

period of juvenility brought about by the thinning treatment resulted in an increased JW proportion. It appears that, as Clark and Saucier (1987, 1989) suggest, planting density can be used to control radial growth and alter the size of the JW core. Also, the application of a thinning after the trees are producing MW at the 1, 1½, or 2 log height level can increase radial growth, after the JW core size is set, and thereby decrease the proportion of JW in the stem. Hence, our results for core diameter and JW proportion appear to reinforce their conclusions. Clark and Saucier (1987, 1989) point out that the general response is toward a decrease in the proportion of cross-sectional area in JW with increasing rotational age. It should also be noted that an increase in rotational age would produce an increase in the proportion of clear wood found in pruned trees and a subsequent increase in value.

Conclusions

1. The ring number and the age at which the transition from JW to MW occurred were not significantly affected by spacing, thinning, or pruning.

2. Butt log JW core diameters were more affected by spacing than second log JW core diameters.

3. There was no consistent trend toward increased JW core diameter with increased spacing.

4. When two-stage pruning with thinning (T2P) was compared with two-stage pruning without thinning (UT2P), the diameter of the JW core did not differ significantly.

5. When one-stage pruning with thinning (T1P) was compared with two-stage pruning (2P), no significant difference in JW core diameter was noted.

6. Two-stage pruning appeared to produce a significantly lower proportion of JW in the lower end of the butt log of the UT2P trees than in the T2P trees, but did not appear to significantly affect the proportion of JW in the upper end of the butt log or the second log.

7. The application of pruning as a one-stage or two-stage process did not appear to significantly alter the proportion of JW within the first two logs.

8. Definite conclusions regarding the affect of thinning and pruning treatments on the proportion of JW are not possible at this time due to the confounding influence of the age 29 thinning treatments. Further analysis of trees harvested in a second sample during December 1989 may help provide the needed clarification.

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SILVICULTURE AND THE RED-COCKADED WOODPECKER: WHERE DO WE GO FROM HERE? [1]

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Abstract. Recent standards and guidelines for the protection and management of red-cockaded woodpecker habitat within 3/4 mi of colony sites, and also thinning within colonies to reduce basal area and midstory will have a significant effect on National Forest lands. The relation of these thinnings to forest pest management will be examined as well as the area of forest involved. Current fire regulations in relation to prescribed burns and potential fuel buildup will be examined. Plans for research, including disturbances, hazard, and risk rating for southern pine beetle and landscape changes will be presented.

Introduction

Cultural practices in southern National Forests, and particularly in eastern Texas, have been affected by litigation stemming from declining populations of the red-cockaded woodpecker (RCW) (Picoides borealis Vieillot). The RCW was identified as a rare and endangered species in 1968 (USDI 1968), and officially listed as an endangered species since 1970 (USDI 1970). The bird received Federal endangered species protection with the passage of the Endangered Species Act in 1973. The USDA Forest Service (FS) in July 1975, amended its Wildlife Habitat Management Handbook to include a chapter on management of the RCW (USDA 1975, Ch. 420). Under authority of the Endangered Species Act, the Fish and Wildlife Service (FWS) approved a RCW recovery plan (USDI 1979). Following approval of the recovery plan in October 1979, the FS revised its Wildlife Habitat Management Handbook, Chapter 420 (USDA 1979). A 1980 rangewide RCW survey (except for the Croatan, Daniel Boone, Oconee, and Ouachi ta National Forests) estimated 2121+/-405 active colonies. This is about 70 percent of the active colonies found on all Federal lands during the 1980 rangewide survey (Lennartz et al., 1983). Using "Continuous Inventory of Stand Condition" information, the FS estimated 2,026 RCW colonies in 1980. These are summarized in Costa and Escano (1989).

Red-cockaded woodpecker populations have declined during the last 20 years, both southwide (Ligon et. al., 1986; Costa and Escano 1989) and in Texas (Conner and Rudolph 1989). As an example, the number of active colonies in the Angelina National Forest in Texas decreased from 38 in 1983 to 19 in 1988 (Conner and Rudolph 1989).

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A number of factors influenced this decline. Red-cockaded woodpeckers are unique in that nesting and roosting cavities are constructed and maintained exclusively in living pine trees, primarily "old-growth" longleaf (Pinus palustris Mill.), loblolly (P. taeda L.) and shortleaf (P. echinata Mill.) pines. Nest cavity trees must therefore have sufficient heartwood to support a nest cavity (Lennartz et al., 1983b; Conner and O'Halloran 1987). Loss of "old-growth" southern pine stands, either to short-rotation forestry or other uses, has resulted in significant loss and fragmentation of nesting habitat (USDI 1985). Hardwood midstory encroachment, resulting from a change in fire regime from periodic hot, growing-season fires to cooler, winter prescribed fires, is also strongly associated with cavity tree cluster abandonment (Locke et al., 1983; Conner and Rudolph 1989). In Texas, another major factor in cavity tree loss is the southern pine beetle (Dendroctonus frontalis Zimm.). Over a 13-year period, over 50 percent of cavity tree mortality in Texas National Forests was due to bark beetles, with significant losses occurring during both epidemic and endemic bark beetle population levels (Conner et al., 1991a). Red-cockaed woodpecker cavity trees are also highly susceptible to windsnap at the point of cavity excavation, accounting for about 30 percent of cavity tree loss in the previously referenced study.

Catastrophic losses to forests also impact the RCW. Most cavity trees lost on the Raven District of the Sam Houston National Forest in Texas occurred during a southern pine beetle epidemic (Billings and Varner 1986; Conner et al., 1991a). This bark beetle epidemic was coupled with Hurricane Alicia in 1983. Losses of 183 RCW cavity trees due to unknown causes were probably due to the southern pine beetle (Conner et al., 1991a). On the Kisatchie National Forest in Louisiana, RCW cavity trees and clusters were lost to a southern pine beetle epidemic followed by fire (Kulhavy et al., in press). Catastrophic losses occurred on the Francis Marion National Forest in South Carolina during Hurricane Hugo, on September 21, 1989.

As a result of lawsuits filed in 1985 against the USDA Forest Service in Texas by the Texas Committee on Natural Resources, the Sierra Club, and the Wilderness Society, on June 17, 1988, Judge Robert M. Parker, U.S. District Court for eastern Texas, issued a permanent injunction against the FS which, among other things, required the following silvicultural activities on National Forests in Texas (impacting about 200,000 ac):

1. Conversion of forest harvesting techniques from even-aged management to a program of selection or uneven-age management that preserves 'old-growth' pines from cutting within 200 m of any colony site.

2. Establishment of a basal area of 60 ft^2/ac, within 3/4 mi (1200 m) of any colony site.

3. Establishment of a program of midstory removal of hardwoods in and adjacent to colony sites.

4. Cessation of the use of existing logging roads or other non-paved roads within colony sites and restrict the use of such roadways to the essential minimum within 3/4 mi (1200 m) of any colony site. (June 17, 1988, opinion and order at 39)

The FS began implementation of these requirements but appealed the judge's decision. Basal area reduction and midstory hardwood removal were carried out on many RCW colonies during the appeals process. On March 4, 1991, the U.S. Court of Appeals for the Fifth Circuit issued a decision that will partially vacate the district court's injunction requiring specific features in the RCW habitat management plan for National Forests in Texas, while upholding the judge's findings that previous forest management in Texas National Forests resulted in a "take" of the RCW, thus violating the Endangered Species Act of 1973. The injunction order was remanded to the district court with the instruction that it review a new RCW management plan to be prepared by the FS. The District Court judge will either approve or disapprove the new plan, which is currently being formulated.

Our research in the National Forests of Texas has focused on site and stand characteristics of RCW colonies and interaction with southern pine beetle in stands composed principally of loblolly and shortleaf pines, stand characteristics, and physiological characteristics of RCW cavity trees have been examined, and silvicultural implications explored.

Hazard Rating for Southern Pine Beetle

Seven active RCW colonies in loblolly and shortleaf pine types in or near the Bannister Wildlife Management Area in the Angelina National Forest were chosen for hazard rating. RCW colonies and surrounding stands were rated using two methods: Texas (TX) Hazard (Mason et al. , 1981) and National Forest (NF) Risk (Lorio and Sommers 1981). Hazard systems are based on stand basal area, land form, tree height and diameter and other relevant stand attributes and rate the susceptibility of stands, based on these characteristics to southern pine beetle. Both systems used in this study produced similar results in Texas and Louisiana (Lorio et al., 1982). Areas within a radius of 1320 ft (402 m) were evaluated for each RCW colony.

Hazard And Risk Rating

Individual colonies (cavity tree clusters) were ranked low to moderate hazard using the TX Hazard system and moderate hazard using the NF Risk system. In 1986, within ¼ mi of the colonies 28 percent of the stands were low hazard, 25 percent moderate, 0.3 percent high, and 7.5 percent extreme with TX Hazard. Four percent were low hazard, 52 percent moderate, and 6 percent high with NF Risk (Mitchell et al., 1991). Average stand characteristics and hazard ratings (TX Hazard) were similar to those reported by Belanger et al. (1988) for RCW colonies in Georgia. Bark beetle infestations, particularly the southern pine beetle, were responsible for mortality of four active, one inactive, and 13 non-cavity trees from 1985-1987. More colony trees were lost in 1985 (an epidemic SPB-year in Texas) than in 1986 and 1987 (years of low population) combined (Mitchell et al., 1991).

Oleoresin Exudation Flow

Pecking of resin wells by the RCW causes copious resin flow. Resin on cavity tree boles acts as a barrier to rat snakes, a major predator of the RCW (Jackson 1974; Rudolph et al. , 1990a). Data on oleoresin exudation flow (OEF), also an important defensive characteristic against southern pine beetle (Hodges et al., 1979; Nebeker et al., 1988; Lorio et al., 1990), were collected periodically during the growing seasons of 1986 through 1989 in the Bannister Wildlife Management Area, and 1989 through 1990 in the Neches District of the Davy Crockett National Forest. OEF was measured by wounding the trees at approximately 4.5 ft (1.4 m) above the ground with a circular arch punch 1 inch (2.54 cm) in diameter driven to the interface of xylem and phloem (after Lorio and Sommers 1986 and Lorio et al., 1990).

A small aluminum funnel was placed immediately under the wound which directed exuded oleoresin into a graduated tube. The OEF measurements were recorded 8 and 24 hours post-wounding. All holes were punched between the hours 0700 to 1000 to minimize effects of diurnal variation (Nebeker et al., 1988). One hole was punched per tree. The bark plug removed by the arch punch was then placed back into the tree. OEF was evaluated on three types of trees: active, inactive, and potential (control). Trees were considered active if they were currently being used for roosting or nesting. Inactive trees had been used for nesting or roosting at some point, but were currently unused by RCW. Potential trees were morphologically similar to cavity trees, but showed no evidence of ever having been used by RCW.

Resin production and resin flow in southern pines is interactive with weather, soil moisture, season, and topographic position (Blanche et al., 1985; Lorio 1986; Lorio and Sommers 1986; Lorio 1988; Lorio et al., 1990). Results from oleoresin exudation flow studies in Texas RCW colonies indicate OEF can also vary with site and species (in this case, shortleaf and loblolly). In the Angelina National Forest, most cavity trees were loblolly pine, but the shortleaf pine exhibited higher OEF. Exactly the opposite occurred in the Davy Crockett National Forest colonies, with shortleaf more common but loblolly showing greater OEF (Ross et al., 1991).

Differences in OEF between cavity tree types varied with site, species, and year of sampling (Mitchell 1987; Ross et al., 1991). Overall OEF trends tend to indicate that newly activated RCW cavity trees have higher OEF, but that the effect when it occurs is transient. (For a more detailed analysis of OEF data, see Ross et al., 1991.)

Plant Moisture Stress

Plant moisture stress was evaluated on selected active, inactive, and potential cavity trees from 1986 to 1989 in the Angelina National Forest, and 1989 to 1990 in the Neches District of the Davy Crockett National Forest. Moisture stress was measured using the pressure chamber technique described by Scholander (1965). Twigs for sampling were collected from the upper crowns of the trees using a 12-gauge shotgun, with moisture status recorded within 60 seconds of removal from tree. Sampling was done between the hours 1300 and 1500.

Pressure chamber readings showed no differences in moisture status that could be detected during peak stress hours. Sampling moisture stress was not as intensive as we would have liked however, due to logistic difficulties and concern about sampling impact on the trees and the birds.

Conclusion

Management for Red-cockaded woodpeckers is ultimately going to have to focus on maintaining the kind of forest ecosystems where they along with other endemic wildlife can thrive. One long-range need is restoration of longleaf pine within its native range. Longleaf, because of its longevity, fire resistance, and resistance to bark beetles and diseases, is frequently recommended as the pine species of choice for RCW (Lennartz et al., 1983a, 1983b; Conner et al., 1991a). Cool winter prescribed burns need to be replaced, where feasible, with hot, growing season fires for control of hardwood midstory, control of hardwood regeneration, and facilitation of pine regeneration (Conner and Rudolph 1989, Costa and Escano 1989).

Management strategies for RCW colonies in shortleaf and loblolly stands should emphasize reducing the risk of bark beetle attack by optimizing general stand health (Conner et al., 1991b; Kulhavy et al., in press; Mitchell et al., 1991). Age, species, and genetic diversity are frequently cited as factors in reducing bark beetle risk (Hicks et al., 1979). Currently, decision notices have been prepared for interim standards and guidelines for the protection and management of RCW within 3/4 mi (1200 m) of colony sites (USDA Forest Service 1991a, 1991b).

Catastrophic disturbances cannot be prevented. However, managers must be prepared to use the most effective methods to prevent cavity tree loss during both epidemic and endemic populations of bark beetles. Direct control methods available in RCW colonies include cut and remove, cut and leave, and cut and chemical spray. Cut, pile, and burn is not permitted in RCW colonies (USDA 1987).

Site specificity is an important consideration in any cultural activity, regardless of goals. Forest managers and wildlife biologists need to have room to use their expertise in deciding when and how to apply thinnings, hardwood midstory control, prescribed fire, and extraordinary measures, such as augmentation and artificial nest cavity construction. For example, tailoring a harvest/regeneration cut or basal area reduction thinning to accomplish their purpose while minimizing wind damage to cavity trees requires site specific management. Harvest/regeneration cutting near RCW cluster areas should emphasize approaches that do not require total forest removal, such as seedtree, shelterwood (Conner et al., 1991b), and selection. An irregular shelterwood system may be appropriate in many situations (Smith 1986).

The interaction of the RCW in the southern pine forest ecosystem is complex and requires the integration of long-term forest management goals with the recovery of the species. The impact of current management (i.e., midstory removal, stand thinning, periodic burns) on the forest ecosystem needs to be further assessed in terms of economic impact and forest succession. The forest created for the RCW will endure for many years, and the benchmark for the species needs to be recorded.

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IMPACTS OF FORESTRY HERBICIDES ON WILDIFE[1]

Karl V. Miller and Jeffery S. Witt[2]

Abstract. Concern over the widespread use of herbicides arises from two factors: potential direct toxicity to wildlife and indirect effects on wildlife habitat. From the results of our studies and other published literature, it is apparent that wildlife habitat is not adversely affected by herbicidal site preparation, except perhaps during the first growing season. Herbicide use at times may be superior to other vegetation management methods in terms of their effects on wildlife. However, the vastly differing plant communities that develop following the use of different chemicals necessitates additional study of their impacts on wild species.

Introduction

Vegetation control with herbicides is a common practice in forest) range, and right-of-way management throughout the United States. Herbicide use has increased in the past decade for several reasons: (1) increased availability of more selective and environmentally compatible chemicals; (2) rising costs of alternative vegetation control methods such as mechanical vegetation management; (3) lack of labor to conduct manual vegetation control; and (4) recognition that herbaceous and woody plant competition reduces early growth of established plantations.

In the Southeastern United States approximately 243,000 ha (600,000 ac) of National Forest lands receive vegetation management annually of which 44,535 ha (110,000 ac) are treated with herbicides (USDA 1988). Concerns over the widespread use of herbicides arise from two factors: potential direct toxicity of selected herbicides or their degradation products to wildlife, and indirect wildlife effects due to habitat alteration. Objectives of this paper are to: (1) briefly review toxicological data pertaining to herbicides commonly used for forestry, range, and right-of-way vegetation management; (2) evaluate published literature on the effects of herbicidal vegetation management on wildlife habitat, and; (3) present results from two studies investigating the effects of chemical vegetation control on wildlife habitat.

Toxicity

Because other authors have provided thorough reviews on the subject, the toxic effects of the various herbicides will not be discussed in detail here (see Weed Science Society of America 1979; Hudson et al., 1984; Morrison and Meslow

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1983; USDA 1984, 1988; Walstad and Dost 1984; McComb and Hurst 1987). In general, much of the public concern over the use of herbicides, and particularly aerial application, stems from their classification as pesticides along with insecticides and fungicides. By definition, herbicides are chemicals designed to control plants by altering their physiology. Since animals and plants share few similar physiological pathways, the toxic effects of herbicides to animals are low. Acute oral toxicities of common forestry herbicides have been summarized (USDA 1988) and range from 375 mg/kg (2,4-D) to 8,200 mg/kg (picloram).

The commonly used forestry herbicides have relatively low mutagenicity and are either non- or weakly oncogenetic (USDA 1988). Mammalian elimination rates are rapid, ranging from ca. 74 percent in 4 days to 100 percent in 48 hours, depending on the chemical. In addition, since these chemicals have relatively low lipid solubility they are not deposited in adipose tissue and do not have a tendency to bioaccumulate in the food chain (Norris 1981). Forestry herbicides also have a short half-life in the environment, ranging from 10 (sulfometuron methyl) to 63 (picloram) days (USDA 1988).

Herbicides And Wildlife Habitat

We conducted a detailed review of literature on the effects of herbicides on wildlife habitat and their uses in habitat management from 1954 to 1989 (Miller et al., 1990). The uses of herbicides in timber, range, right-of-way (ROW) management, and wildlife habitat enhancement were emphasized. Two hundred ninety-three publications were recovered representing 165 specific research investigations. General discussions and reviews accounted for 37 publications.

Of 48 studies investigating the use of herbicides in wildlife habitat enhancement, 34 cases were rated as successful, 10 as qualified successes, and four as unsuccessful. When compared to mechanical methods, herbicidal vegetation control in timber management benefitted wildlife habitat in 19 studies, had little or no effect in 22 studies, and adversely affected wildlife habitat in 10 studies. Similarly, herbicide use in range management benefitted wildlife in 15 studies, had little or no effect in 16 studies, and adversely affected wildlife habitat in 13 studies.

Of 241 herbicide evaluations, 124 (51 percent) reported the effects of 2,4-D and/or 2,4,5-T (or 2,4,5-TP). Numbers of studies investigating the wildlife habitat implications of other herbicides were low: glyphosate 16, picloram 15, ammate 10, tebuthiuron 10, hexazinone 8, and others.

Our review emphasizes that there is relatively little information on the indirect effects of herbicides on wildlife species, particularly endemic and migratory threatened and endangered species. There is a broad assortment of herbicides registered for controlling herbaceous and woody competition on forest sites. The replacement of mechanical vegetation management with herbicides may produce large-scale vegetation shifts. The magnitude and duration of these shifts, in relation to wildlife food and shelter requirements, are not completely understood and are poorly documented. Also, the selectivity of alternative herbicides could produce plant diversity changes that might affect wildlife. The importance of these changes in relation to wildlife food and cover requirements is not completely understood and requires additional study.

The few studies conducted to date indicate that herbicidal vegetation management may not adversely affect wildlife habitat to a large extent and often may actually improve conditions for wildlife. However, the selectivity of many newer herbicides necessitates additional studies to determine and analyze important changes in plant succession which may affect key wildlife species. This information is necessary to guide forestry use of herbicides, and determine the real environmental impacts of alternative vegetation management practices.

Specific Studies

We conducted two studies to evaluate how different forest herbicides affect wildlife habitat and habitat composition, primarily when used as site-preparation treatments. Our studies were conducted in the sandhills of the Upper Coastal Plain of South Carolina and in the Georgia Piedmont.

Upper Coastal Plain Study

On an Upper Coastal Plain site in Barnwell County, South.Carolina, two chemical site preparation treatments were compared with a mechanical site preparation. The plantation was divided into three areas. During summer 1987, Area 1 received an aerial application of picloram (Tordon™) (2.24 kg ai/ha) plus fluroxypyr (3.24 kg ai/ha). Hexazinone (Pronone 10G™) was applied to Area 2 at 2.8 kg ai/ha with an Omni™ spreader. Area 3 was mechanically site prepared by roller-chopping. All areas were burned during October 1987 and loblolly pine (*Pinus taeda*) seedlings planted in February 1988. Four 1-m² plots were randomly selected near each of four random sites on each area. Percent vegetation cover by species was estimated on each plot. Plots were clipped and dry weight by species determined.

Grasses, primarily *Cynodon dactylon, Panicum* spp., and *Andropogon* spp., were the predominant vegetative type on the chemically treated sites. Mean percent cover and biomass of grasses on Areas 1 and 2 exceeded those on the mechanically treated site (Table 1).

Legumes were more abundant on the hexazinone treatment than on the other chemically treated site or the mechanical area. Total forb production was higher on the roller-chopped site than on the chemically treated areas. Dominant forbs on the chemically treated sites included *Lespedeza* spp., Cassia *fasciculata, Diodia teres, Tragia urens,* and *Croton glandulosus*. Predominant species on the roller-chopped area were *Erigeron* spp., *Ipomoea* spp., *Lechea villosa,* and *Diodia teres*. Woody vegetation (vines, shrubs, trees) also was most abundant on the mechanically treated area vs. Area 1 or 2.

Wildlife habitat values of site preparation methods vary with the habitat requirements of the particular wildlife species. Forb and woody vegetation production on the roller-chopped area provided abundant forage for

Table 1. Mean percent cover and total biomass of four vegetative categories on chemically and mechanically site prepared pine plantations in the Upper Coastal Plain of South Carolina.

Treatment	Type of measure[1]	Vegetative class: Grasses	Forbs	Woody vines	Trees and shrubs
Picloram	Percent cover	32.4	9.1	3.9	1.9
+ fluroxypyr	Biomass [2]	914.0	222.3	70.8	38.9
Hexazinone	Percent cover	28.6	17.7	3.5	5.0
	Biomass [2]	736.6	287.1	24.9	220.3
Roller-chop	Percent cover	11.1	27.1	6.2	8.3
	Biomass [2]	222.3	992.8	182.4	177.4

[1] See text for application rates
[2] Dry matter

white-tailed deer (Odocoileus virginianus). Although total production of forbs and woody vegetation was less on the chemical areas, several preferred forb species were as abundant or more abundant. The hexazinone-treated area produced the greatest amount of legumes favored by bobwhite quail (Colinus virginianus). The heavy grass cover on the chemically prepared sites likely favored many rodent species and provided summer foraging sites for wild turkey (Meleagris gallopavo). The presence of snags on these areas provided habitat for several cavity-nesting or bark foraging birds as well as perches for raptors.

Piedmont Study

In a second study we evaluated the response of wildlife food plants to various mechanical and chemical site preparation treatments at 2-4 years post-treatment in the Georgia Piedmont. Study areas consisted of two sites in Putnam County and one site in Monroe County, Georgia. Chemical treatments examined included imazapyr, triclopyr, picloram plus triclopyr, and hexazinone. Ocular estimates of percent cover by species were taken at three heights (0.0, 0.5, and 1.0 m) on 48 systematicaly located 1-m^2 sample plots per site.

We categorized plant species as quail foods, soft mast, and winter browse. Our results suggest that although vegetation catergory means were variable among sites, treatments, and age classes, trends in vegetation responses may be present (Table 2). At age 2, percent cover by quail food plants on the imazapyr treatments were greater than the control or other chemical treatments. Quail food plants at age 3 were more abundant in the intensive mechanical site treatments, while hexazinone treatments tended to enhance the production of quail foods at age 4. Soft mast and winter browse were higher in the hexazinone treatment at age 2, control and triclopyr treatments at age 3, and triclopyr treatments at age 4.

Table 2. **Mean** percent ground cover of three classes of vildlife plant foods **on mechanically and** chemically site prepared pine plantations **in the** Georgia Piedmont.

Years post-treatment	Treatment	Application rate	Wildlife food category: Quail food	Soft mast	Winter browse
		(L/ha)			
2	Picloram + triclopyr	14.0 + 4.7	3.2	4.5	0.9
					9.9
	Imazapyr ne	2.3 16.4	12.0 15.1	10.5 15.8	2.0
	Intensive mechanical[1]	---	7.3	6.8	5.8
	Control[2]	---	8.5	13.2	14.1
3	Picloram + triclopyr	14.0 + 4.7	2.9	6.6	4.0
	Hexazinone	9.4	1.2	16.0	14.3
	Triclopyr	9.4	3::	12.9	12.5
	Intensive mechanical.	---		7.9	5.4
	Control[2]	---	3.2	10.7	7.7
4	Eexazinone	14.0	5.7	3.9	5.2
	Triclopyr	9.4	3.7	5.2	2.1
	Control [3]	---	2.4		1.4

[1] Mechanical treatments included shearing and root raking.

[2] Control plots were roller-chopped.

[3] Control plots vere untreated.

From the results of our studies and others in the literature, it is apparent that at least some aspects of wildlife habitat are not adversely affected by herbicidal site preparation, except perhaps during the first growing season post-treatment. Herbicides provide a shift in plant species composition from one dominated by woody plants to one dominated by forbs. In most cases, this shift results in much higher habitat value for wildlife. In addition, certain herbicides may enhance the production of valuable wildlife plant forages. For example, sites prepared with hexazinone often produce an abundance of legumes that are important wildlife plants and also nitrogen fixers. Imazapyr also promotes legumes and, in addition, it is not particularly effective against blackberries (Rubus spp.)--another important wildife food plant.

Conclusions

The use of herbicides for vegetation management is not as detrimental to wildlife habitat as once assumed. In fact, the use of herbicides often may be superior to other vegetation management methods in terms of their effects on wildlife. Herbicides should be regarded as a tool for use by forest and wildlife managers. However, they are not the only tool available. All man-caused activities in forested systems can impact wildlife habitat, and it is important to understand the results of these activities.

The selectivity of the newer generations of herbicides offers exciting possibilities regarding their potential uses. The differing plant communities that develop following the use of different chemicals necessitates additional study of their impacts on wild species. However, provided suitable data is obtained, it may one day be possible to tailor both types and rates of herbicide application to not only achieve vegetation management goals, but also selectively enhance or reduce populations of focal wildlife species.

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THE INFLUENCE OF THE PRICE-SIZE CURVE ON PLANTING DENSITY DECISIONS [1]

Jon P. Caulfield, David B. South, and Greg L. Somers [2]

Abstract. Financial returns from plantation investments are influenced by a multitude of factors. These include planting density, rotation age, site index, planting and management costs, product price and whether or not thinning is carried out. The optimal planting density, in turn, is influenced by the price-size relationship existing between the tree crop being grown and products that can be sold. This paper discusses several types of price-size relationships which can exist and the kinds of situations to which they may apply. The influence of these different price-size curves on planting density decisions for nonthinned loblolly pine (*Pinus taeda* L.) plantations is also examined.

Introduction

Several researchers have examined the question of optimal economic planting density. The work of Bowling (1987) and Conrad et al. (1990) employ case studies based on results from experimental plot data. Other studies, notably those of Borders et al. (1991), Hotvedt and Straka (1987), and Broderick et al. (1982) are based on the results of computerized growth and yield models. A variety of economic and biological assumptions are built into all of these studies. Not surprisingly, therefore, no universal agreement exists regarding what constitutes an optimal planting density.

Bowling (1987), using a replicated slash pine (*Pinus elliotii* Engelm.) spacing study in Georgia, showed that densities as low as 400 trees/ac may be appropriate when products such as chip-and-saw and sawtimber can be merchandised. Similar conclusions were reached by Conrad et al. (1990) for a nonthinned loblolly pine (*P. taeda* L.) plantation. Their analysis of a spacing study in Mississippi showed that the lowest density examined, 484 trees/ac, resulted in greatest economic returns when multiple products were considered.

Other research indicates that economically-optimal planting density varies within wide limits. Borders et al. (1991), for example, showed that on site index (SI) 60 land, the appropriate density for nonthinned loblolly pine can range from 500-1100 trees/ac when factors such as variable site preparation, planting, and transportation costs are accommodated.

Hotvedt and Straka (1987) reports that planting densities from 750 to 950 trees/ac combined with thinning led to the highest economic returns. Broderick et al. (1982) also recommended thinning to maximize investment returns.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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However, they also recommended planting at much lower densities (436 trees /ac).

The work of Hotvedt and Straka (1987) differs from other work because their analysis employs a residual value approach to timber valuation. They obtain stumpage values by subtracting manufacturing, transportation and harvesting costs from end-product prices, to derive "returns-to-tree" curves for trees of differing dbh. In other studies, prices are typically assumed constant for a given class of product, regardless of tree diameter.

Methods

Price-size Relationships

The shape of a price-size curve depends on the intended end-product of the trees being cut. The simplest case is a horizontal line of price per unit volume over dbh. This implies that tree size does not influence the stumpage price paid per unit volume. A horizontal price-size curve may be appropriate when trees are grown exclusively for pulpwood. In this study, two different horizontal price-size curves were examined for pulpwood (Fig. 1). These assume pulpwood is valued at $25/cunit and $50/cunit, respectively. The lower price reflects 1990 average prices in southern Alabama as reported in Timber Mart-South (1990).

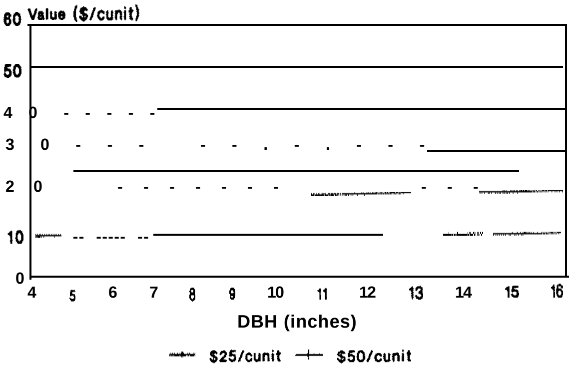

Figure 1. Price-size curves, pulpwood only.

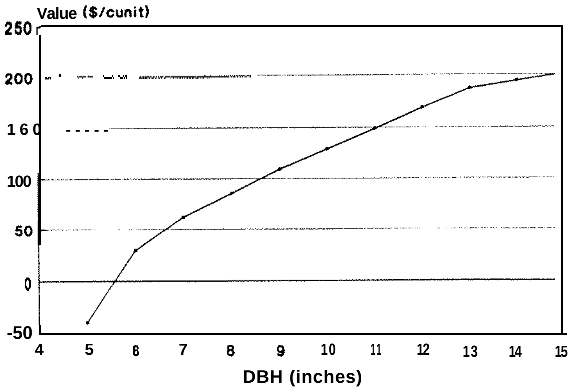

Figure 2. Marshall price-size curve.

A positively sloped price-size curve implies that trees are used for increasingly higher-value products as dbh increases and/or that harvesting and transportation decrease on a per-unit volume basis with increasing dbh. Two multiple-product curves are considered here.

Marshall (1990) derived price-size relationships using the residual value method. He determined stumpage value by beginning with sawn timber values and subtracting milling costs, losses from sawing, transportation and harvesting costs. His sawmill cost curves were derived from a hypothetical sawmill study. He presents the curves on a per-tree basis. These were converted to a per-cunit basis for this study. Unlike the return-to-tree curves derived by Hotvedt and Straka (1987), which did not value trees < 9 inches dbh, Marshall included stems as small as 5 inches dbh. Since such small trees are typically valued as pulpwood, his analysis includes a wider range of product classes (Fig. 2). In his analysis, it was assumed that the minimum small-end diameters were 3 and 6 inches for pulp and sawtimber, respectively.

The Marshall curve is appropriate for use by integrated forest products firms that purchase wood from their own woodlands or from private landowners. But the majority of timberlands in the South are owned by nonindustrial owners. Most of these landowners do not have access to the type of mill study required to derive the Marshall and Company price-size curves. For these individuals, price-size relationships require a different approach.

A price-size curve derived from Timber Mart-South appears in Figure 3 (the TMS curve). This was derived using 1990 stumpage prices for pulp, chip-n-saw and sawtimber in Southern Alabama. It assumes that trees with 5-inch dbh and larger can be utilized as pulp to a 4-inch top. Chip-n-saw can be cut from trees with 8-inch dbh and up to a 6 inch top; and sawtimber can be cut from trees with 12-inch dbh and up to an 8-inch top.

The TMS curve is flat for trees 5 to 8 inches dbh because only pulp can be cut from such trees. For trees 8 inches and larger, however, the curve steps up, then has a positive slope up to 12 inches. As trees become merchantable for sawtimber, the curve again steps up and has a positive slope. The positive slopes which follow the upward steps occur because as trees enter successively higher value categories part of the tree can be sold as pulp and part as sawtimber. For example, an 8-inch tree can be sold partly as small sawtimber and partly as pulp. A lo-inch tree, however, has a greater proportion of higher value CNS relative to pulp. Its value, calculated as a weighted average of the pulp and chip-n-saw material, is greater than that of an 8-inch tree.

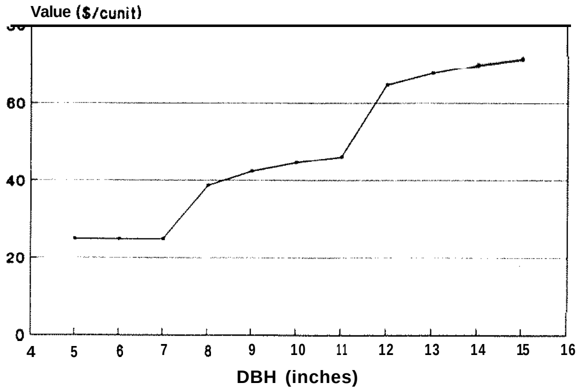

Figure 3. Timber Mart-South (TMS) price-size curve.

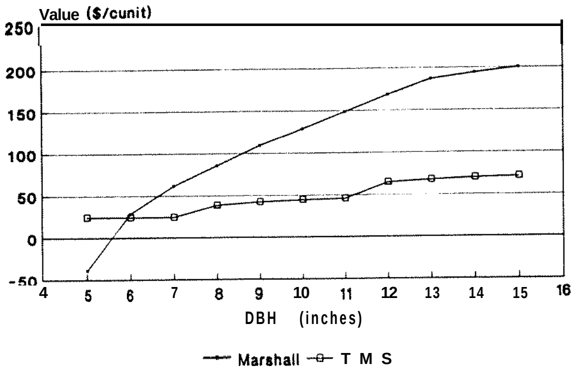

Figure 4. Multiple-product price-size curves.

The two multiple product price-size curves described above appear in Figure 4. There is considerable diversity between the per cuni t values for different size trees. The curves are not directly comparable because different assumptions regarding merchantability limits, stumpage price regions, and type of timber seller were applied to each one. The intent here is not to compare the curves to one another. Rather, they are used to first show how price-size relationships can vary depending on the timber seller or buyer. Second, as shall be seen, the type of curve employed influences planting density decisions.

Generation of Stand Values

For each price-size curve the optimum rotation age was calculated using the band Expectation Value (LEV) criterion for each of a set of different initial planting densities. The N.C. State Growth and Yield Simulator (Hafley and Smith 1989) was used to generate stand tables for each possible rotation age, at each density, for a given site index. The data in that model include spacing studies with densities as low as 300 trees/ac. This was used to define the minimum density examined here, and thereby avoided extrapolating beyond the model data set.

Planting densities examined were 300, 350, 400, 450, 500, 600, 700 and 900 trees/ac. The optimum rotation for a given density is the age at which LEV is at a maximum. band expectation value is the discounted value of the net returns from an infinite series of identical rotations (Clutter et al., 1983). A 6-percent real discount rate was employed in the base-case and LEVs are calculated on a before-tax basis. The analysis assumes that there is no increase in real prices of any product. A SI of 60 at age 25 is employed for the base-case. Stand values at each age were determined by summing the product of the cunit volume for the trees in each l-inch diameter class by appropriate per-cunit prices. It was assumed that 1st year survival of planted trees was 85 percent, and that survival percentage did not vary with planting density.

In calculating the LEVs, it was recognized that planting costs vary with different planting densities. Seedlings were valued at $0.028 each and planting cost $0.058 per seedling. Site preparation was assumed to be constant for each planting density and consisted of chemical site preparation plus burning at $91.34/ac (Straka et al. 1989).

An assumption implicit to this analysis is that wood quality of trees grown at low densities does not differ from those grown at higher densities. Evidence exists to suggest that wood quality from fast-growing trees suffers little from the standpoint of specific gravity (Clark and Saucier 1989, Zobel and Talbert 1984). Also, for slash pine, the production of dimension lumber meeting the SPIB "dense" classification was not strongly influenced by wide spacings (Bennett 1969). But wide spacings do result in larger knots, and presumably, a decrease in wood value (Bennett 1969). Therefore, while the importance of wood quality is recognized, it is beyond the scope of this study.

Sensitivity Tests

As indicated previously, the planting density decision is influenced by a number of interrelated factors. To examine one of these, SI is varied. In addition to the base-case SI of 60, SIs of 50 and 70 were evaluated.

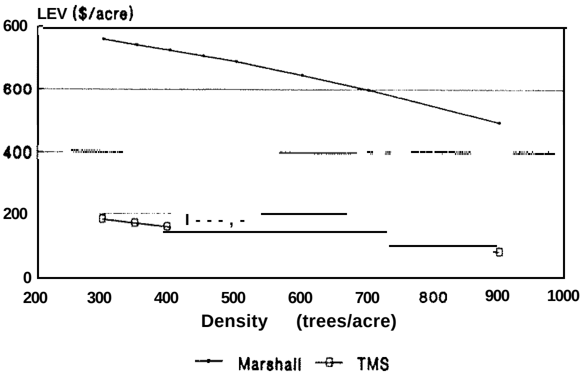

Figure 5. Land expectation value (LEV) over density, base case, multiple-product, price-size curves.

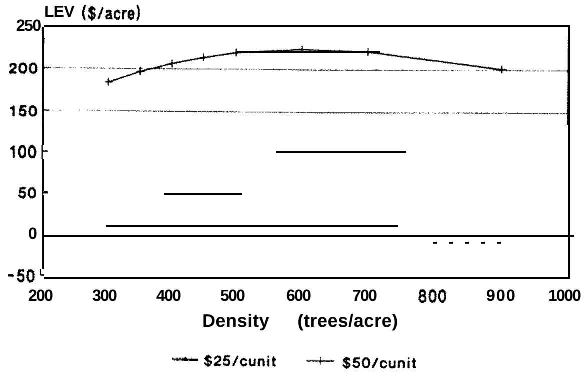

Figure 6. Land expectation value (LEV) over density, base case, pulpwood price-size curves.

Results and Discussion

Base-case

Figure 5 shows the relationship between LEV and planting density for the base-case, multiple product price-size curves. For the Marshall and TMS price-size curves, LEV is at a maximum at 300 stems/ac and decreases with increasing density.

Table 1 shows these relationships more distinctly and includes the rotation age at each density level for which LEV is at a maximum. Although a density of 300 trees/ac was optimal for both multiple product curves, the decrease in LEV going from 300 to about 400 trees/ac is small. For the Marshall and TMS curves, the decrease is 5 and 10 percent, respectively. As density increases beyond 400, the percentage decrease in LEV gets larger. For a density of 900 trees/ac, the decreases are 36 and 43 percent, compared with the lowest density.

Several implications can be drawn from Table 1. First, an upward sloping price-size curve suggests that lower planting densities may be preferable to higher planting densities. In each case the lowest density examined had the highest LEV. But, for a fairly wide range of densities the reduction in LEV is minor. This suggests that foresters who regularly realize survival rates lower than the 85 percent assumed here may be justified in planting at higher densities for that reason alone.

Figure 6 shows LEV over density for the pulpwood only price-size curves, using the base-level assumptions. With pulpwood at $25/cunit, LEV is maximized at 450 stems/ac. At $50/cunit, LEV is maximized at 600 trees/ac. For flat price-size curves, optimal planting densities tend to be higher than when curves slope upward. For the pulpwood curves the optimal planting densities in each case (450 and 600, respectively) are higher than for the Marshall and TMS curves.

Table 2 shows an interesting result . At 450 trees/ac the optimal density for lower-price pulpwood ($25/cunit) is considerably lower than for the higher-price pulpwood. This implies that planting density is influenced not only by the slope of the curve, but by the absolute magnitude of stumpage prices as well.

Table 1. Land expectation values and optimal rotation ages for multiple-product price-size curve, base-case. [1]

Density	Rotation age	Marshall	Rotation age	Timber Mart-South
	(yr)	(LEV $/ac)	(yr)	(LEV $/ac)
			31	
300	30	758 *	30	184 *
350	29	739		174
400	29	723	29	164
	28		28	156
600	27	[illegible]	27	149
700	27	599 645	2626	140
				120
900	27	496	26	79

[1] SI 60 (base 25), 6 percent real discount rate, 85 percent first-yr survival, before-tax analysis. Optimal density denoted by asterisk.

Table 2. Land expectation values and optimal rotation ages for pulpwood price-size curves, base-case. [1]

Density	Rotation age	$25/Cunit	Rotation age	$50/cunit
	(yr)	(LEV $/ac)	(yr)	(LEV $/ac)
300		17	26	
350	2626	19	25	184196
400	21	25	24	206
450	2.5	22 *	24	214
600	25	21	24	219
700	24	17 9	2323	221 224 *
	24			
900	24	-13	23	201

[1] SI 60 (base 25), 6 percent real discount rate, 85 percent first-yr survival, before-tax analysis. Optimal density denoted by asterisk.

In this case the planting density decision is driven more by cost and the discounting period than by timber value. The lower cost of planting fewer trees impacts the density decision more at lower stumpage prices. A lower stumpage price for a given product will increase the optimal rotation age (Chang 1984), so establishment costs are compounded over a longer period. In sum, the combined affect of a lower stumpage price, lower cost, and the resulting longer rotation imply a lower planting density.

Although optimal planting densities are derived for the two pulpwood price-size curves, there is a fairly wide range of densities within which the change in LEV is minor. As with the other multiple product curves, the implication is that when lst-year survival is expected to be lower than 85 percent, planting at higher densities may be appropriate.

Sensitivity Tests

Decreasing site index to 50 ft (vs. 60 ft for the base-case) decreased volume at each age and density , and increasing SI to 70 increased volume. LEV decreased and increased, respectively, in each case. For the positively sloped Marshall and TMS curves, the planting density decision was unaffected. The optimal density remained at 300 trees/ac for all SI levels examined (Table 3). These relationships can be seen in Figures 7 and 8. Each figure shows that when the price-size curves had a fairly steep positive slope, the density decision was not sensitive to SI, for the range of densities examined.

The flat price-size curves were more sensitive to changes in SI. Optimal density went from 300 trees/ac for the $25/cunit curve at SI 50 to 500 at SI 70 (Fig. 9). Note, however, that at SI 50 all LEVs were negative at a 6-percent rate meaning that a density of 300 trees/ac simply resulted in the smallest monetary loss. This indicates that at low prices and low SI levels, the density decision is cost-driven.

Table 3. Sensitivity analysis results from changing site index assumptions from base-case.[1]

Site index		Marshall	TMS	Pulp at $25/cnt	Pulp at $50/cnt
	Highest LEVs, optimal densities and rotations				
50	Density	300	300	300	500
	LEV	324	30	-43	72
	Age	32	34	30	26
60	Density	300	300	450	600
	LEV	758	184	22	224
	Age	30	31	25	23
70	Density	300	300	500	600
	LEV	1318	384	102	369
	Age	28	28	23	22

[1] Base-case assumes SI 60, 6 percent real discount rate, 85 percent first-year survival, before-tax analysis.

For the $50/cunit curve, the optimal density was as high as 600 tpa for SI 60 and 70 (Fig. 10). This suggests that the planting density decision is more sensitive when the price-size curve is flat, versus the situation when the curve has a steep upward slope. Although the densities differ, the general results here are consistent with the work of Borders et al. (1991). In their paper, increasing SI resulted in an increase in optimal planting density. As in the base-case, however, the difference between LEV for the optimal density and a wide range of densities was small. For example, at SI 50 for the Marshall curve, there is only a 10 percent decrease in LEV as density goes from 300 to 500 trees/ac. For SI 70, the decrease is 9 percent. This suggests that considerable leeway exists in density decisions when the assumptions regarding survival rates differ from those here.

Summary and Conclusions

The price-size relationship which prevails for a specific ownership situation has a decided influence on the planting density decision. The analysis indicates that for nonthinned loblolly pine plantations, fairly low planting densities may be appropriate when multiple-product, positively sloped price-size curves apply. Lower densities may also be warranted when the price-size curve is flat and under conditions of low stumpage prices. It is important to recognize that these results hinge on the assumption that low densities do not negatively impact wood value due to quality problems.

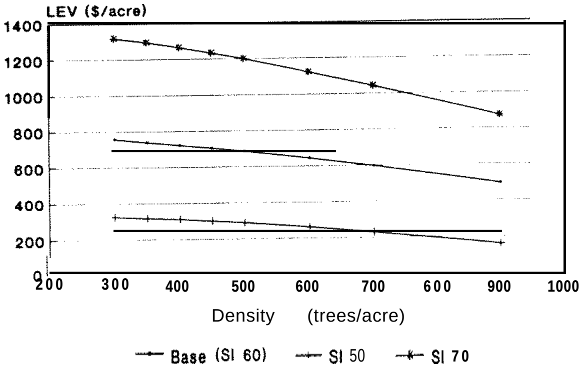

Figure 7. Land expectation value (LEV) over density, Marshall price-size curve, for three levels of site index.

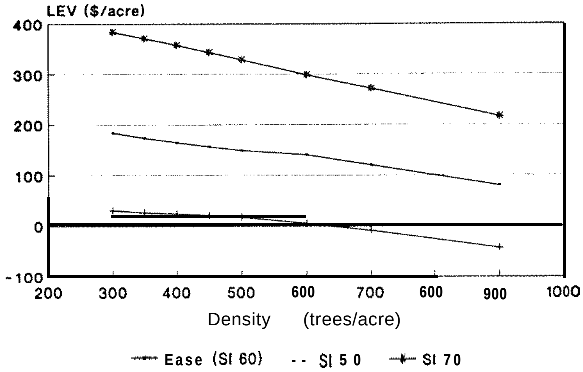

Figure 8. Land expectation value (LEV) over density, Timber Mart-South price-size curve, for three levels of site index.

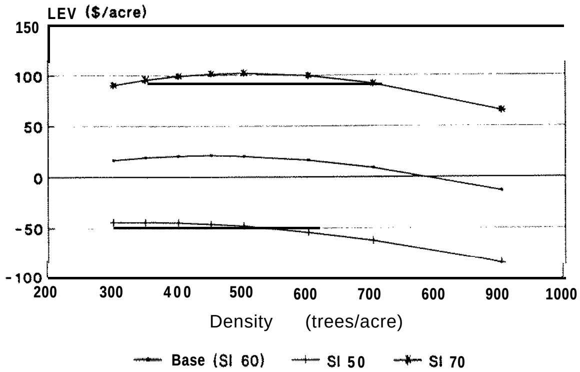

Figure 9. Land expectation value (LEV) over density, pulpwood price-size curve at $25/cunit for three levels of site index.

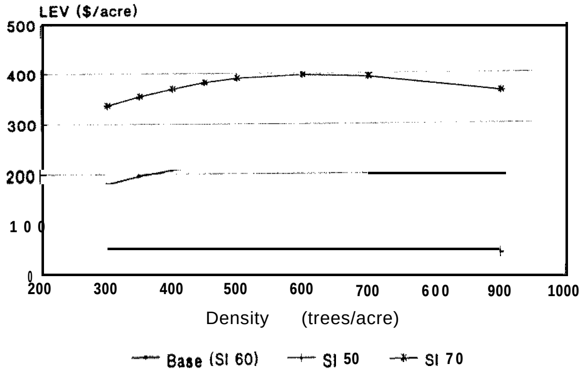

Figure 10. Land expectation value (LEV) over density, pulpwood price-size curve at $50/cunit for three levels of site index.

The results suggest lower densities than those recommended by some researchers (Borders et al., 1991; Hotvedt and Straka 1987), but are consistent with the findings of others (Broderick et al., 1982; Bowling 1987; Conrad et al. , 1990). Obviously, the growth and yield model employed along with the biological and economic assumptions built into any analysis will influence the results. This study employed a different growth and yield model than any of the work cited which relied on computerized projection models. It is therefore interesting to note that the results here are in fairly close agreement to research which relies on experimental plot data.

Few industrial timber growers currently plant trees at stockings as low as 300 trees/ac, even where low prices prevail. There are several reasons for this. First, foresters frequently argue that more stems are needed in case survival is low. Also, planting at low densities may lead to increased weed competition and therefore reduced growth of the tree crop. Both are reasonable arguments, but Bredenkamp et al. (1983) has suggested that with respect to loblolly and slash pine, trying to control weeds with stand stocking is poor silviculture. Future research will more completely answer these questions.

Results from this analysis raise another issue. The forestry community often criticizes nonindustrial owners who practice extensive forest management. Even those owners who consciously regenerate cut areas sometimes employ very low-cost methods which may, due to chance or design, result in low pine stocking. When such tracts of timber are located in low stumpage price areas, landowners may be behaving far more rationally than the foresters give them credit.

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PROFITABILITY OF HARDWOOD AND HERBACEOUS WEED CONTROL IN LOBLOLLY PINE STANDS [1]

Donald G. Hodges [2]

Abstract. The profitability of controlling hardwood and herbaceous weed competition was evaluated for selected loblolly pine (*Pinus taeda* L.) stands in Tennessee and Virginia. Empirical data were utilized to evaluate the economic desirability of hardwood control. Herbaceous weed control effects were simulated by reducing rotation lengths. Hardwood control was a profitable management practice for the three study sites. Herbaceous weed control alone was economically feasible if the increased growth reduced rotation length by at least 2 years. For most of the management regimes evaluated, combined hardwood and herbaceous weed control yielded the largest economic returns.

Introduction

Forest industries constitute the largest sector of the South's economy in terms of employment, salaries, and wages. The southern pines support most of this industry, comprising approximately two-thirds of the annual roundwood harvest volume, and 74 percent of the annual product value (USDA Forest Service 1988). Some recent Forest Service resource surveys, however, indicate that softwood inventory growth in the region is declining. One of the primary factors in the decline is the failure to reestablish pine stands after harvest . The South's Fourth Forest report (USDA Forest Service 1988) indicated that 6.1 million ac could be improved through stocking control or pine release. Failing to apply sound vegetation control practices on these lands could result in significantly reduced growth rates and the loss of pine forests.

Foresters have realized the value of pine release for some time. Hardwood herbicides have been available for decades, but herbaceous weed control (HWC) research and methods are relatively new. In fact, most herbicides that provide low-cost alternatives for controlling herbaceous weeds (i.e. , non-woody annual or perennial plants) have been developed only recently. While land managers have long recognized the importance of site preparation for pines, research in the past decade has demonstrated that pine growth can be increased significantly if HWC is applied for several years after planting. Few comparisons have been published on the economic returns of increased timber volume resulting from investments in hardwood and herbaceous weed control. The principal objective of this study was to evaluate

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costs and returns associated with herbicide applications for controlling both hardwood and herbaceous weed competition in loblolly pine (Pinus taeda L.) stands.

Prior Research

Researchers have evaluated the biological response of pine to competition control extensively in the past 10 years. The findings indicate that controlling either hardwood or herbaceous vegetative competition enhances early pine growth substantially. Recent studies suggest that this growth differential may last long into the pine stand's rotation (Glover et al., 1989). Moreover, evaluations of specific herbicide treatments reveal that such practices are economically efficient (Guldin 1984, 1985; Anderson and Hickman 1986; Busby 1989).

Controlling vegetative competition increases pine growth and yield significantly. Glover and Dickens (1985) reported that pine yields on stands with 30 percent hardwood basal area yield 50 percent less pine volume than similar stands with a 4 percent hardwood basal area component. The substantial gains in pine growth resulting from chemical HWC have been documented only recently. As with hardwood control herbicides, several effective HWC herbicides have been developed and registered. Studies have demonstrated that HWC positively influences growth response in loblolly, longleaf (P. palustris Mill.), and slash (P. elliottii Engelm.) pines (Minogue et al., in press). This response may vary by site quality, treatment, species, and level of herbaceous competition. Height growth is significantly greater in treated stands than in untreated stands (Knowe et al., 1985; Zutter et al., 1988). In most studies, the greatest increased growth has been observed in diameter. Michael (1985), for example, reported that one treatment of a HWC chemical (sulfometruon methyl) increases the groundline diameter (gld) of treated pines 80 percent more than in untreated pines; height growth increases by 21 percent.

Response by loblolly pine to combining woody and herbaceous control is similar to the above results. Three study areas were established in Virginia to evaluate the impact of varying the level of vegetation competition control (Bacon and Zedaker 1987). The levels of control included herbaceous control only, woody control at three, levels only, and herbaceous plus woody control. With all levels of competition control, diameter and volume growth increases significantly after three growing seasons. In each of the 3 years after treatment, total control of all competition and herbaceous control plus two-thirds control of the woody competition results in significantly greater diameter growth than on the untreated plots. Volume growth exhibits a similar trend. Two-year-old seedlings display the greatest response. Overall, the best response is with the herbaceous plus two-thirds woody vegetation control. No significant gains in height growth were reported. The volume growth curves are still diverging after 3 years, indicating that these impacts continue long into the stand's rotation. Other studies have yielded similar results (Miller et al., 1987; Swindel et al., 1988).

Research Approach

Response to herbaceous weed control has been modeled by two methods in the past. The first alternative assumes that HWC increases site index. Thus biological response is simulated by increasing the site index in growth and yield projections for the weed control samples (Daniels and Burkhart 1975, Clason 1989). The second alternative is to reflect the response to weed control by shortening the rotation (by up to 3 years) (Busby 1989, Teeter and Huang 1989). The shortened rotation appears to be the more plausible approach. As Busby (1989) notes, the primary effect of HWC is to release seedlings from weeds earlier and provide a faster start for the stand.

This study used a shortened rotation to model the effects of HWC. Specifically, the impact of controlling herbaceous weeds was simulated conservatively by shortening rotation lengths by 1 and 2 years. Hardwood control effects were taken from existing empirical studies. The study used these biological yield estimates, herbicide treatment and other management costs, and stumpage prices to evaluate the returns to weed control.

Study Sites

The study utilized data from Glover and Dickens (1985), who summarized results of 27 studies located on forest industry or other organization land where alternative vegetation control methods were evaluated. Three of the 27 sites were selected for this analysis for several reasons, Only sites where hardwood control had been evaluated were considered. A number of the hardwood control sites were eliminated because additional cultural treatments had been conducted, which would confound the analysis.

Three hardwood control sites located in Tennessee and Virginia were selected for the analysis. Table 1 lists the stand characteristics of the sites. Site index values were calculated for each site based on Amateis and Burkhart (1985) equations, and ranged from 52 to 57 ft at age 25. Only one of the sites, Rochelle, required any appreciable site preparation. Velpar Gridball™ was applied on all three sites. Timing of the application of chemical HWC ranged from 2 to 5 years after planting.

Management Costs

Costs for the various management practices were based on averages reported by Straka et al. (1989). Disking costs for the Rochelle site were estimated at $65/ac, based on region-wide averages for similar site preparation practices. Planting costs were based on a regional average for machine planting old-fields. Seedling costs were estimated as $30/thousand seedlings.

Hardwood control costs of $55/ac were used in this study. Analysts have reported higher costs (Clason 1989), but the lower costs were justified. Straka et al. (1989) reported a 13-percent decline in chemical treatment costs in 1988, with many hardwood control costs being less than $55/ac. HWC was estimated at $25/ac. This price is similar to those reported by Busby (1989) for spot treatments of weeds and Clason (1989) for band treatment. No price or response differentials were modeled for

Table 1. Study site information.

Site 1.	Grass Creek- King and Queen County, VA Site index: 52 ft History: planted 1974; treated 1979; measured 1983 Treatment evaluated: 1.25 lb Velpar, 2 cc pellet Initial stand information (1983): Control plot: 36.9 percent hardwood; basal area- 69.1 ft^2 Trees/ac- 760 pine, 2183 hardwood Treated plot: 16.8 percent hardwood; basal area 63.3 ft^2 Trees/ac- 760 pine, 1333 hardwood
Site 2:	Rochelle- Hardin County, TN Site index: 52 ft History: disked, planted 1976; treated 1978; measured 1983 Treatment evaluated: 1 lb Velpar, 2 cc pellet Initial stand information (1983): Control plot: 47.1 percent hardwood; basal area- 36.5 ft^2 Trees/ac- 460 pine, 580 hardwood Treated plot: 1.3 percent hardwood; basal area 30.0 ft^2 Trees/ac- 460 pine, 580 hardwood
Site 3:	Waddels- New Kent County, VA Site index: 57 ft History: planted 1977; treated 1980; measured 1983 Treatment evaluated: 1.25 lb Velpar, 2 cc pellet Initial stand information (1983): Control plot: 50.8 percent hardwood; basal area- 40.4 ft^2 Trees/ac- 635 pine, 446 hardwood Treated plot: 9.4 percent hardwood; basal area 40.4 ft^2 Trees/ac- 635 pine, 446 hardwood

Source: Glover and Dickens (1985)

different treatment types, since the primary concern was to adequately represent the costs associated with shortening rotation length by HWC. A miscellaneous annual management cost of $2 was also included to cover regular management expenses. All costs were assumed to increase by 1 percent above inflation/yr.

Yields And Stumpage Prices

Evaluating the returns to investments in competition control requires obtaining data that adequately reflect the biological response to herbicide treatments. A growth and yield computer program was used to project the biological response to chemical hardwood treatments, because no long-term response data exist. The growth and yield model by Hafley et al. (1982) was selected because of its explicit consideration of a stand's hardwood component. The program was developed with data collected from loblolly pine stands throughout the South that exhibited a wide range of hardwood competition. The biological response to HWC was simulated by shortened rotation lengths, as described above.

Prices used in the analysis represent the 1988 average stumpage prices for the southern United States, as reported in Timber Mart-South. The averages are similar to the average prices reported for Tennessee and Virginia--location of the three study sites. Sawtimber stumpage was valued at $115/thousand bd ft (MBF), chip-n-saw at $30/cord (cd), and pulpwood at $11/cd. Prices were assumed to increase by 1.5 percent above inflation each year.

Additional Considerations

Land expectation value (LEV) was the decision criterion used to evaluate alternative weed control scenarios. LEV is defined as the net present value of bare land producing perpetual rotations of even-aged timber. Additional factors considered in the analysis include three rotation lengths (20, 25, 35 years) and two real discount rates (4 and 6 percent). To simplify the analyses, the 20- and 25-year rotation alternatives were evaluated with no thinning. A thinning at year 20 was included in the 35-year rotation option.

Results

Controlling vegetative competition clearly affects the volume yield and economic returns for loblolly pine. These results are discussed below. First, the volume yields for no competition control and hardwood control are presented. The profitability of herbaceous weed control only, hardwood control only, and combined competition control are then evaluated.

Yields

The results from the growth and yield projections illustrate how chemical hardwood control can affect product yields (Table 2). As expected, sawtimber yields increased with both hardwood control and longer rotation lengths. Pulpwood yields declined, as more volume shifted from small diameter to sawtimber-sized trees. The largest percentage increases in sawtimber volume were projected for the lower site quality stands. Sawtimber yields increased by 100 to 350 percent on the Grass Creek and Rochelle sites, while the Waddels site sawtimber volume increased by 36 percent for the 35-year rotation. The two lower quality sites still produced less sawtimber and chip-and-saw volume than Waddels.

Herbaceous Weed Control Only

Figures 1 through 3 depict the land expectation values, calculated at a 4-percent real discount rate, for the three sites and for different treatments. Land Expectation Values were estimated for no weed control, herbaceous weed control only (1- and 2- year reductions in rotation length), hardwood control only (no rotation length control), and combined hardwood and herbaceous weed control (again, 1- and 2- year reductions in rotation). The first set of bars in Figures 1-3 depict land expectation values for no weed control; the second set represents LEVs for a l-year rotation reduction due to herbaceous weed control ("1-YR Red"); and the third set, a 2-year reduction ("2-YR Red"). The results illustrate that on lower quality sites, herbaceous weed control profitability depends on the site and rotation age. HWC alone was not economical on any of the scenarios developed on the Grass Creek or Rochelle sites, but was profitable on the Waddels site if rotation age was reduced by 2 years. Land expectation values with HWC were 1 to 3 percent larger on Waddels than without treatment.

Hardwood Control Only

The hardwood control only bars in Figures 1-3 ("Hdwd Control") illustrate that significant increases in economic returns can be earned by controlling hardwood competition only. The lower quality sites, Grass Creek

Table 2. Results of growth and yield projections.

Site/treatment	Rotation length	Sawtimber (mbf)	C-N-S	Pulpwood
	- (yr) -	- (mbf) -	---- (cd)	------
Grass Creek				
No weed control	20	0.0	3.0	16.3
	25	0.0	7.0	16.0
	35	0.6	9.1	10.2
Hardwood control	20	0.0	5.2	17.7
	25	0.2	10.3	17.6
	35	1.2	13.8	12.5
Rochelle				
No weed control	20	0.0	4.7	12.1
	25	0.2	8.9	12.1
	35	1.3	10.7	9.0
Hardwood control	20	0.0	7.8	11.2
	25	0.9	12.0	10.9
	35	3.5	14.0	9.9
Waddels				
No weed control	20	0.2	8.0	10.7
	25	1.1	10.6	10.3
	35	2.8	12.0	7.0
Hardwood control	20	0.2	10.7	16.0
	25	1.3	14.9	15.8
	35	3.8	19.2	10.5

and Rochelle, generally exhibited larger changes in LEV value than Waddels. For the 25 and 35 year rotations, LEV increases ranged from 24 to 93 percent for Grass Creek, 37 to 135 percent for Rochelle, and 33 to 99 percent for Waddels. The land expectation values for the 20-year rotation increased significantly for only the Waddels site. Part of the increased response for the 20-year rotation may be attributed to the differences in site quality. That is, higher quality sites are able to respond to control treatments quicker than lower quality sites, and therefore, will exhibit greater economic returns for short rotations. Another factor in the large response is that the Waddels site possessed a greater decline in the hardwood component after treatment (from 50.8 to 9.4 percent hardwood) than the other two sites. This clearly is not the sole factor, however, since Waddels did not maintain the increase over the three rotation lengths evaluated.

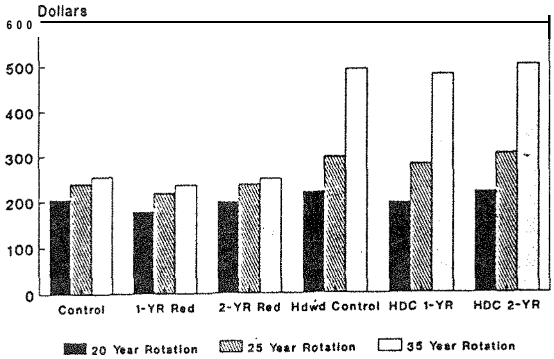

Figure 1. Land expectation values for alternative competition control regimes, Grass Creek site, 4 percent real discount rate.

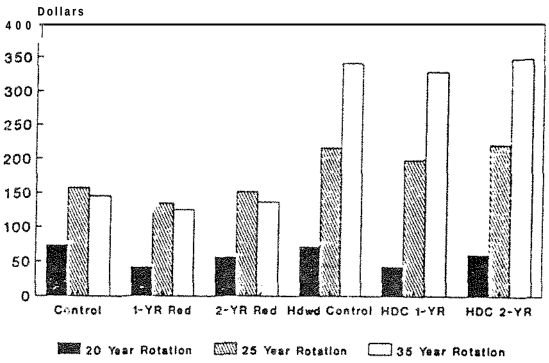

Figure 2. Land expectation values for alternative competition control regimes, Rochelle site, 4 percent real discount rate.

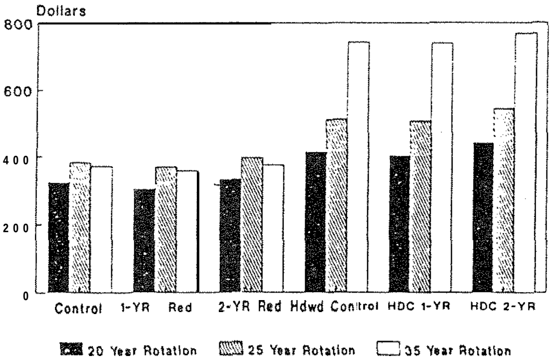

Figure 3. Land expectation values for alternative competition control regimes, Waddels site, 4 percent real discount rate.

Hardwood and Berbaceous Weed Control

The final two sets of bars on Figures l-3 depict the land expectation values when both hardwoods and herbaceous weeds are controlled. For the 25- and 35-year rotations, the combined control (with a 2-year reduction in rotation length) represented the largest LEV option for all but one case. While all combinations resulted in significant increases in LEVs, hardwood control only was more profitable than hardwood and herbaceous weed control (l-year reduction) for all sites. This was primarily due to the large response to hardwood control only and the minimal effect of herbaceous weed control (l-year reduction) only discussed earlier. Clearly for the sites used in the evaluation, hardwood competition was a major limiting factor in growth.

Changes in Discount Rate

As expected, increases in the real discount rate reduced the land expectation values. In this case, an 6 percent real discount rate resulted in reduced or negative LEVs. Real internal rates of return for most simulations ranged from 5 to 10 percent. The relative ranking of LEVs remained relatively unchanged with regard to cultural treatment and rotation length, for Waddels. The most profitable management alternatives for the Grass

Creek and Rochelle sites did change, however. Generally, less intensive regimes became more profitable on these low quality sites with a larger discount rate.

Conclusions

Results of the study illustrate several important considerations in evaluating competition control alternatives. First, hardwood control significantly enhanced the profitability of southern pine management. In the cases examined, chemical hardwood control increased land expectation values by up to 130 percent. Hardwood competition detracts from economic returns by limiting diameter growth. The largest impacts from controlling competition, therefore, would occur in cases with a substantial percentage of sawtimber--longer rotations. As the study demonstrated, reducing hardwood competition had the greatest influence on rotations that allow the released pines adequate time to fully occupy the site.

A second result of the study involves the profitability of controlling herbaceous weeds. In most instances, HWC must reduce rotation lengths by more than one year to be profitable. HWC became very attractive on all sites with a 2-year rotation length reduction. Although, a 2-year reduction in rotation length was modeled, some studies have indicated that the reductions may be larger (see, for example Nelson et al., 1981). A reduction of more than 2 years would assure that herbaceous weed control was profitable for most of the alternatives examined.

Combining hardwood and HWC proved to be the most-profitable management alternative for most cases. It was not substantially more profitable than hardwood control only, however. All three sites examined had large hardwood components. Velpar was effective in reducing the percentage of hardwood significantly. Much less is known about the impact of HWC on the sites examined. The assumption made in this analysis was that HWC would influence the profitability by reducing rotation length. No assumptions concerning increased quality from weed control were considered. It is generally agreed that hardwood control affects both growth and wood quality. Little is known about the cumulative effects of HWC. As better data become available, a more definitive answer regarding the total impact of HWC and combinations of hardwood and weed control will be possible.

The study also highlighted several research needs. The most obvious is a more comprehensive examination of the volume growth impacts of controlling hardwoods, herbaceous weeds, or a combination of the two. At the present time, much of the HWC information is based on very young stands. The quality of the data will naturally improve as the stands mature and the data base expands. A related shortcoming of the current data is the lack of research concerning the influence of the timing and intensity of the competition control treatments on economic returns. More controlled trials aimed at comparing hardwood weed control alternatives will help improve estimation of the profitability of chemical treatments.

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ECONOMIC RESIDUAL STAND STRUCTURE GOALS FOR SINGLE-TREE SELECTION IN CENTRAL APPALACHIAN HARDWOODS [1]

Gary W. Miller [2]

Abstract. Periodic harvests in hardwood stands managed under single-tree selection can be controlled by using residual stand structure goals to guide marking. Cut trees are marked to achieve a desired number of residual trees per acre in each diameter class, which provides for both regeneration after each harvest and sustained yield of wood products. A practical method for defining the most profitable residual stand structure is presented. This technique utilizes a linear programing model to solve for cutting cycle length and residual number of trees in each dbh class. Constraints such as minimum residual basal area and largest diameter tree can be added for multiple objectives. The impact of adding basal area, largest tree, and diameter-distribution constraints are evaluated.

Introduction

Single-tree selection often is regarded as the preferred method for applying an unevenage management system in Appalachian hardwoods. Harvests remove periodic merchantable volume growth and provide space so that reproduction can be established and residual trees can continue to grow into larger diameter classes for future harvests. Each harvest is made up of mature trees and high-risk, low-quality trees selected from all merchantable diameter classes. Cut trees are marked to achieve a desired number of residual trees per acre in each diameter class--a residual stand goal which provides for both reproduction and sustained yield of products.

Smith and Lamson (1982) described how to apply selection harvests in Appalachian hardwoods. Number of residual trees in each dbh class is determined by desired residual basal area (RBA), largest diameter tree (LDT), and a tree distribution quotient (q-value) used to give the residual stand distribution curve a reversed J- shape (Figure 1). Quotients are found by dividing the number of trees in each dbh class by the number of trees in the next larger dbh class. The average of quotients throughout all dbh classes is the q-value. By specifying RBA, LDT, and q-value, the forest manager can define a goal for the number of residual trees as a guideline for marking the stand. Trees then are harvested from dbh classes in which there are surplus trees--more than enough to meet the goal. Where there are deficits, a few extra trees can be retained in the next smaller dbh class to eliminate the deficits as trees grow into larger dbh classes (Figure 1).

Practical, single-tree selection guidelines were developed from

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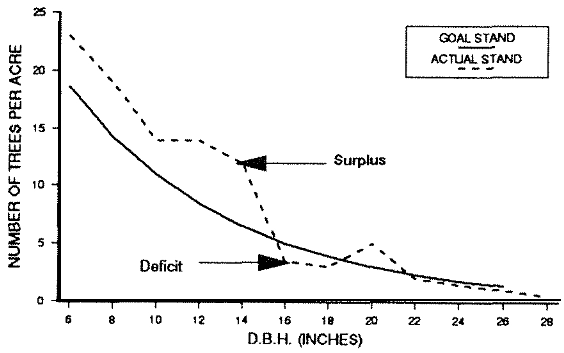

Figure 1. An example of a residual stand structure goal compared with actual stand structure from cruise data.

stands managed under single-tree selection for sawtimber production on the Fernow Experimental Forest near Parsons, West Virginia. Smith and Lamson (1982) provided tables containing over 400 different residual stand goals and recommended a particular goal for each of three site indexes. Field studies have shown that recommended residual stand goals are workable and pro-. vide regular commercial sawtimber harvests (Smith and Miller 1987). However, suggested goals were developed to achieve silvicultural objectives, and thus may not be optimal in terms of economic objectives. Other goals may provide for regeneration and sustained yield while offering a higher financial return.

This paper presents a practical method for defining the most profitable stand-structure goal in Appalachian hardwoods managed under single-tree selection. A linear programing model is used to maximize net present value (NPV) considering RBA, LDT, and q-value constraints imposed by the forest manager. The impact on NPV is evaluated for each constraint, indicating the cost of imposing such limitations on the stand. The effect of cutting cycle length also is evaluated.

Data

Growth equations used to define economic stand structure goals were derived from data obtained in Appalachian hardwood stands managed under single-tree selection over a 40-year period. Study stands received three or four single-tree selection harvests planned on a lo-year cutting cycle before data were collected. A total of 20 permanent ½-ac growth plots provided 5-year growth data on individual trees. Study areas were located on northern red oak site indexes 70 and 80.

On 10 study plots, individual trees were measured immediately following a periodic harvest and again 5 years later. This part of the data provided growth observations at residual basal area levels characteristic of selection stands just after a harvest. On another 10 plots, measurements were taken 5 years after harvest and again 10 years after harvest, representing the second 5-year period in the cutting cycle. This part of the data provided growth observations at slightly higher stocking levels characteristic of managed stands in the middle years of a cutting cycle.

Growth Model

Growth rates of individual trees were modeled by estimating the probability of a tree's, (1) surviving the growth period and remaining in the same dbh class, (2) surviving the growth period and growing into the next larger dbh class, or (3) dying during the growth period. Transition probabilities for the survivor trees were expressed as a function of initial basal area (IBA), residual basal area (RBA), and initial dbh (D). Probabilities (P) were estimated using a logistic function as follows

$$P = \frac{1}{1 + \exp - [B_0 + B_1 \text{ IBA} + B_2 \text{ RBA} + B_3 \text{ RBA}^2 + B_4 \text{ D} + B_5 \text{ D}^2]} .$$

Ingrowth (I) into the smallest dbh class was expressed as a linear function of residual basal area (RBA) as follows

$$I_{t+5} = B_0 + B_1 \text{ RBA}, .$$

Stand growth is estimated by multiplying the initial number of trees in each dbh class by the appropriate transition probabilities and adding estimated ingrowth to the smallest dbh dlass. The initial stand distribution is given by a vector, y_t, containing the number of trees in each dbh class at the beginning of a 5-year growth period. Stand structure at the end of the growth period is given by a vector, y_{t+5}, computed using the following matrix form (Buongiorno and Michie 1980, Solomon and others 1987)

$$\begin{vmatrix} y_{6,t+5} \\ \cdot \\ \cdot \\ \cdot \\ y_{26,t+5} \end{vmatrix} = \begin{vmatrix} a_6+d_6 & d_8 & \cdot & \cdot & d_{26} \\ b_6 & a_8 & 0 & 0 & 0 \\ 0 & b_8 & a_{10} & 0 & 0 \\ 0 & 0 & \cdot & \cdot & 0 \\ 0 & 0 & 0 & b_{24} & a_{26} \end{vmatrix} * \begin{vmatrix} y_{6,t} - h_{6,t} \\ \cdot \\ \cdot \\ \cdot \\ y_{26,t} - h_{26,t} \end{vmatrix} + \begin{vmatrix} c \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} .$$

A general expression of this linear growth model is given by

$$Y_{t+5} = G * (Y_t - h_t) + c$$

which also defines sustained yield equations in a general economic model used to find optimal single-tree-selection goals.

Periodic harvest is given by a vector, h_t, whose elements are the number of trees to be cut in each dbh class. Transition probabilities expressing mortality, movement of survivor trees into larger dbh classes, and ingrowth into the smallest dbh class are given by a matrix, G. The first row of the G matrix contains the slope coefficient and basal-area-per-tree factors used to estimate ingrowth. The intercept term in the ingrowth equation is given by a vector, c. In the G matrix, a_6 is the probability that a 6-inch tree will survive and remain in the 6-inch dbh class, and b_6 is the probability that a 6-inch tree will survive and grow into the 8-inch class. In the first row of G, d_6 equals the product of the B_1 slope coefficient from the ingrowth equation and basal area of a tree at the midpoint of the (i-inch dbh class. The first element in the c vector equals B_0, the intercept term from the ingrowth equation.

Economic Model

A general linear model for optimizing single-tree selection management was developed by Buongiorno and Michie (1980). The model solves for residual number of trees in each diameter class, given cutting cycle length. Sustained yield constraints assure that the residual stand and marked cut are the same at each periodic harvest once the goal stand structure has been reached. The linear growth model under optimal sustained-yield management becomes the following

$$y^* = G * (y^* - h^*) + c .$$

Note that the optimal solution consists of values for the initial stand structure and periodic harvest vectors. The difference between these vectors is the residual stand structure goal used to guide marking of the cut.

The economic model for defining residual stand structure goals can be written as a linear programing problem

$$\text{MAX NPV} = \frac{(v'h^* - F)}{(1 + r)^n - 1} - v'(y^* - h^*)$$

$$\text{Subject to:} \quad G h^* + (I - G) y^* = c$$
$$y^* - h^* \geq 0$$
$$h^* \geq 0 .$$

Solutions to this problem maximize the present value of timber harvests on a perpetual cutting cycle. The first term in the objective function is the present value of all periodic harvests that result from the optimal residual stand structure in year zero. The second term in the objective function is the opportunity cost of leaving the optimal residual stand in year zero to initiate perpetual cutting cycles. In the objective function, v is a vector of tree values in each dbh class, F is a constant fixed cost associated with each periodic timber sale not affected by the number of trees cut, r is the discount rate, and n is the number of years between periodic harvests. Tree values in this study were derived from tree value conversion standards which account for the value of lumber products contained in a tree minus conversion costs such as logging and milling (DeBald and Dale 1990). Fixed cost included inventory, marking, and other charges associated with administering a timber sale.

The first set of constraints, derived from the linear growth model, assures sustained yield. Additional constraints assure that the residual stand and harvest are non-negative. Other constraints which restrict the q-value, residual basal area (RBA), and largest diameter tree (LDT) can be added as follows

$$q\,(y_{i+1} - h_{i+1}) - (y_i - h_i) = 0$$

$$b_i\,(y_i - h_i) - RBA = 0$$

$$y_{LDT} - h_{LDT} \geq N$$

$$y_{i>LDT} - h_{i>LDT} = 0\ .$$

For these constraints, q equals the desired q-value, b_i is the basal area per tree in dbh class i, and N is the minimum number of trees per acre desired in the LDT class.

In this study, a separate linear programing model was constructed for 10-, 15-, and 20-year cutting cycle problems. Problems were solved using LINDO on a PC microcomputer.

Results

The simplest form of the selection-management model, which included only sustained-yield equations as constraints, maximized NPV by making periodic diameter-limit harvests (Table 1). For the 10- and 15-year cutting cycles, the model suggested cutting all trees 22- inches dbh and larger, leaving a residual basal area of about 80 ft^2/ac in both cases. The average q-value was 1.18 for a 10- year cutting cycle and 1.26 for the 15-year cutting cycle, although the actual quotients among diameter classes varied from 1.1 to 1.6. For the 20-year cutting cycle, the model maximized NPV with a 20-inch diameter-limit, a residual basal area of 66 ft^2, and an average q-value equal to 1.21.

Residual stand structures were similar for the three cutting cycles examined, differing only by harvest of the 20-inch trees in the 20-year cutting cycle. The model recommended a lower diameter-limit for the 20-year cutting cycle to reduce the cost of holding the residual stand an extra 5 years. The 20-inch trees are nearing financial maturity, meaning the average real rate of return over a 20-year period drops below an accep table rate. Thus, NPV is higher for the 20-year cutting cycle if 20-inch trees are harvested. In this situation, the benefits of harvesting 20-inch trees outweigh the cost of holding them an additional 20 years. Figure 2 demonstrates how NPV changes according to cutting cycle and minimum dbh harvest limit . Note that NPV peaks at a lower dbh harvest limit for the 20-year cutting cycle.

Adding Constraints

Constraints were added to the basic sustained-yield model to achieve specific residual stand structure objectives. For example , a largest tree constraint was introduced to ensure that the residual stand contains at least a desired number of trees in the LDT dbh class. In general, increasing the LDT reduced NPV. By holding larger trees, carrying costs increased more than harvest revenues, so there was a net reduction in discounted values.

Table 1. Economic residual stand goals per acre with only sustained yield constraints-diameter-limits.

	Cutting cycle					
	10 years		15 years		20 years	
Dbh	cut	residual	cut	residual	cut	residual
	trees/ac					
6		23.2		22.6		23.7
8		16.3		15.8		16.5
10	-	12.7		12.3	-	12.6
12		10.6		10.2		10.4
14	-	9.4		9.0		9.2
16	-	8.6		8.2	-	8.3
18		8.0	-	7.7		7.8
20	6.5	-7.7		7.3	7.3	–
22			6.8		6.2	–
24	3.1		5.0		3.9	–
26			1.9		1.2	
Total	9.6	96.5	13.7	93.1	18.6	88.5
BA	ft^2/ac					
	26.9	83.4	40.7	80.1	49.0	65.7
Volume	Mbf/ac					
	4.3	7.8	6.6	7.5	7.9	5.0
NPV	$433		$419		$402	

In practice, largest tree constraints are usually accompanied by q-value and residual basal area constraints to fully define residual-stand goals. Various combinations of LDT and q-value constraints were added to the selection management model to evaluate their effect on NPV and periodic harvest. The model configured in this way solved for the most economical residual stand structure goals and RBA simultaneously. NPV was maximized with a q-value of 1.2, LDT of 20 inches, RBA of 75 ft^2/ac for a lo-year cutting cycle when stand-structure constraints were added to the basic sustained yield model. Adding the q-value and LDT constraints reduced NPV from $433 to $404/ac compared with a 22-inch diameter-limit harvest when the model contained only sustained yield constraints. Including the additional constraints also revised the periodic harvest to include some trees in the 14-to 20-inch dbh classes (Table 2), thus departing from a strict diameter-limit practice.

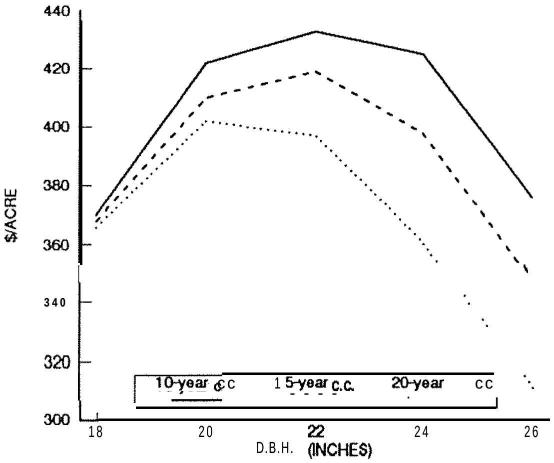

Figure 2. Maximum NPV with sustained yield by diameter-limit and cutting cycle.

Although the model maximized NPV with a diameter-limit practice, there are some distinct advantages to removing high-risk and poor-quality trees throughout all merchantable diameter classes when periodic harvests are made. Samples of butt-log grade taken during preharvest inventories over a 30-year period provided a basis for comparing the effects of selection and diameter-limit cutting on stand-quality development (Fig. 3). Percent of board foot volume in grades 1 and 2 trees (highest grades) fluctuated in unmanaged stands and in stands managed using an 18-inch diameter-limit practice.

Table 2. Economic residual stand goals per acre with q-value, LDT, and RBA constraints- single-tree selection.

	Cutting cycle					
	10 years		15 years		20 years	
Dbh	cut	residual	cut	residual	cut	residual
	trees/ac					
6		24.4	-	23.8	-	24.7
8	-	17.1	-	16.6	-	17.2
10		13.2	-	12.9	-	13.1
12		11.1		10.7	-	11.0
14	0.4	9.2	0.5	8.9	0.8	9.6
16	0.7	7.7	0.9	7.4	1.2	8.4
18	0.9	6.4	1.2	6.2	1.5	6.5
20	1.0	5.2	1.3	5.1	6.4	–
22	4.8		5.4		4.6	–
24	2 1		3.7	–	2.8	–
26	9.9	94.3	14.4 1.4	91.6	18.2 0.9	–
Total						87.9
BA	ft²/ac					
	24.5	75.0	37.8	73.0	37.9	65.0
Volume	Mbf/ac					
	3.8	6.4	5.9	6.2	7.1	4.5
NPV	$404		$399		$385	

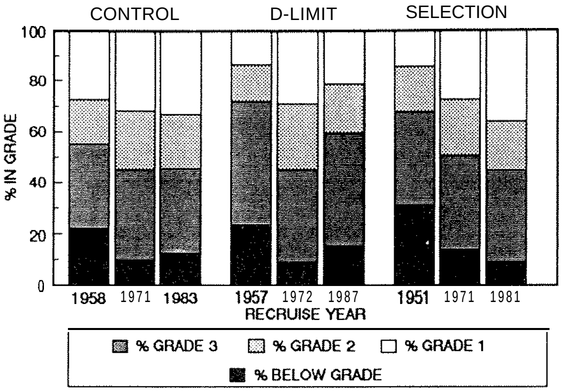

Figure 3. Distribution of sawtimber volume by butt-log grade.

However, in selection stands there was a distinct improvement in quality over 30 years. Each harvest removed trees of lower grade, leaving behind trees with the greatest potential for making grade 1. Over the period of comparison, volume in grades 1 and 2 increased by 35 percent in selection areas, and only 15 to 20 percent in diameter-limit areas. The stand structure goal recommended by the selection-management model (Table 2) will lead to an economical selection practice, and Figure 3 illustrates the importance of harvesting some trees in the immature merchantable size classes at each harvest. Improving immature stems promotes higher quality, and higher value products in later harvests.

In study stands, periodic selection harvests with ground skidding equipment did not result in severe damage to residual growing stock (Lamson, et al., 1985). Residual stand structure goals require about 100 trees/ac in the l.O-to 4.9-inch dbh class to provide for adequate tree recruitment into larger size-classes. In four selection stands examined for damage, the residual stand contained over 250 saplings per acre with no damage of any kind. For the poletimber and sawtimber, there was an adequate number of undamaged residual stems in all size classes to continue future selection harvests.

Evaluating various LDT and q-value combinations for a lo-year cutting cycle revealed some interesting trends (Table 3). For LDT between 20 and 22 inches, lower q-values maximized NPV. As q-value increased for a given LDT, NPV decreased and the optimal RBA also decreased. As discussed for the simplest model structure, holding of large additional trees reduced NPV. When q-value is increased, the model compensates by lowering the RBA to avoid holding larger trees and to enhance the growth of immature stems.

For larger LDTs, NPV is maximized at higher q-values. For example, if LDT equals 26 inches, NPV increases with q-value and peaks at a q of 1.3 (Table 3). The optimal RBA at this combination is equal to 80 ft^2/ac. For larger LDTs, even larger q-values and lower basal areas maximized NPV.

Table 3 shows present-value tradeoffs associated with LDT, q-value, and RBA combinations for Appalachian hardwoods on site index 70 for red oak. For example, esthetic and recreation goals may require relatively large residual stems. Note that maximum NPV drops by $96 per acre if LDT is increased from 20 to 26 inches dbh The forest manager can weigh this reduction in value against the benefits associated with retaining larger trees for noncommodity outputs. The key is to evaluate selection alternatives relative to their effect on NPV.

Table 3. Maximum NPV and optimal RBA for combinations of q-value and LDT on a 10-year cutting cycle.

LDT		q-value 1.2	1.3	1.4	1.5	1.6
inch		------------	ft²/ac, $/ac	------------		
20	BA[1]	75	67	60	55	50
	NPV[2]	404	362	325	294	269
22	BA	80	72	64	57	52
	NPV	388	361	323	292	26%
24	BA	81	77	67	59	54
	NPV	349	354	321	291	267
26	BA	83	80	69	61	55
	NPV	271	308	295	276	258

[1]BA includes all residual trees 5.0 inches dbh and larger.
[2]NPV based on 4 percent real discount rate.

Comparison with Existing Guidelines

From this analysis, it is clear that many single-tree selection alternatives may be successfully applied in the field. In fac t , many combinations of q-value, LDT, and RBA resulted in positive present values, indicating rates of return above an acceptable level. However, adding constraints or adjusting the stand structure away from the optimum reduces NPV, perhaps lessening returns more than is necessary to achieve multi-resource objectives.

Current single-tree-selection guidelines for Appalachian hardwoods on red oak site-index 70 are a q-value of 1.3, LDT of 26 inches, and RBA of 65 ft^2/ac. The model constrained to these specifications resulted in an NPV of $252/ac. Recall that the most economical selection goal was a q-value of 1.2, LDT of 20 inches, and RBA equal to 75 ft^2/ac which maximized NPV at $404. The existing guidelines could be modified in several ways. For example, NPV could be increased to $308/ac by increasing the RBA to 80 ft^2/ac, holding LDT and q-value at their existing levels. LDT and q-value could also be adjusted to increase NPV, so long as other objectives, such as esthetics, are not compromised.

A comparison of current stand structure guidelines and economic guidelines developed in this study are presented in Figure 4. The economic goal includes more residual trees in the 6-to-20-inch dbh classes. Although the economic goal does not include residual trees larger than 20 inches dbh,

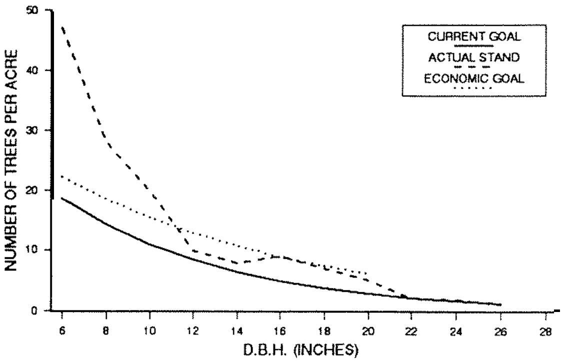

Figure 4. A comparison of current and economic goals with actual stand structure after four periodic harvests.

residual basal area is 10 ft²/ac greater than the current goal. Note that actual stand structure, after five periodic lo-year harvests, is very near the current goal, with some surplus trees in the 16-to-20-inch dbh classes. Relative to the economic goal defined in this study, the actual stand has slight deficits in the 12- and 14-inch dbh classes, and surplus trees larger than 20 inches dbh. The actual stand also contains surplus poletimber trees because harvests in the study stands include only sawtimber trees 11.0 inches dbh and larger.

Figure 4 also illustrates how stand structure goals can be adjusted after several periodic harvests in response to new information or evolving ownership objectives . The economic goal can be achieved in future harvests by retaining additional 12- and 14-inch trees and removing trees 22 inches dbh and larger.

Discussion

Stand structure goals for single-tree selection can be defined using other sources of growth information. The selection- management model originally described by Buongiorno and Michie (1980) utilized mean proportions from observed plot data for transition probabilities in the growth matrix. This method allows for stochastic solution procedures because standard errors of the mean proportions provide a measure of dispersion. Alternatively, transition probabilities can be developed from regression equations based on observed plot data as was done in this study. Many types of growth models can be used to simulate stand growth and derive transition probabilities for defining the growth matrix and sustained-yield constraints in the selection management model.

Results presented in this study are applicable to central Appalachian hardwoods similar to the study stands which provided data for the growth matrix. However, the linear structure of the selection-management model is quite flexible. Management guidelines can be updated periodically to adjust for price changes or long-term fluctuations in dbh growth as species composition changes. Adjustments are made by updating the growth model and selection-management model, and solving for new stand structure goals. As new information on stand development is obtained, stand structure goals for selection can be refined to reflect more accurately the actual growth in particular groups of stands. Also, a similar model to the one used in this study could be developed for optimizing selection practices on local forests where growth transition probabilities can be estimated.

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INCORPORATING RISK INTO SITE PREPARATION DECISIONS [1]

Harold E. Quicke, Jon P. Caulfield, and David B. South [2]

Abstract. Operational data on the survival rate of pine 1 year after planting were obtained for 514 stands in the coastal plain of Alabama. The data were used to identify the most efficeint site preparation methods. For each stand the maximum possible financial return was calculated and the analysis based on a comparison of the distributions of financial returns for each method. Site preparation influences the financial return directly through the cost of the specific type of site preparation employed, and indirectly through the effect of survival rate on the optimum rotation length and volume production. Distributions of financial returns were compared using the mean-variance rule and stochastic dominance analysis.

Introduction

An important reason for site preparation is to ensure adequate survival of planted seedlings. And any decision concerning site preparation methods necessarily involves uncertainty because survival rates are unknown in advance. A manager may, however, have past records available of survival rates following planting for different site preparation methods on sites similar to the one currently under consideration. In this case, the site preparation decision involves risk. Decision making under risk occurs when managers select between alternatives with outcomes which are not known in advance with certainty, but which have known probability distributions of outcomes (Knight 1921).

In the simplest case, the alternative with the highest mean survival rate may be selected. The advantages of this type of analysis include ease in performing, there is only one correct answer, and by calculating the mean the decision maker implicitly recognizes that risk is involved. This simple analysis may, however, result in an incorrect choice.

The first problem with an evaluation of alternatives based on mean survival rate is that it does not account for the variability of possible outcomes: all outcomes other than the mean are ignored. A different decision may be made if the entire distribution of possible outcomes for different types of site preparation on similar sites are compared.

A second problem is that survival rate may not be the appropriate criteria to use when one is interested in maximizing the financial return from the investment. Lower survival rates do not necessarily result in lower financial returns.

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Analyses should therefore be based on expected cost and revenue stream over the entire rotation. Site preparation influences financial return directly through cost of the specific type of site preparation employed, but indirectly as well through the effect on volume production and optimal rotation length.

Our purpose is to review decision making under risk and to demonstrate how risk can be incorporated into site preparation decisions. We do not undertake a rigorous analysis of the financial implications of different site preparation methods, nor should our results be interpreted as a blanket recommendation for any particular methods.

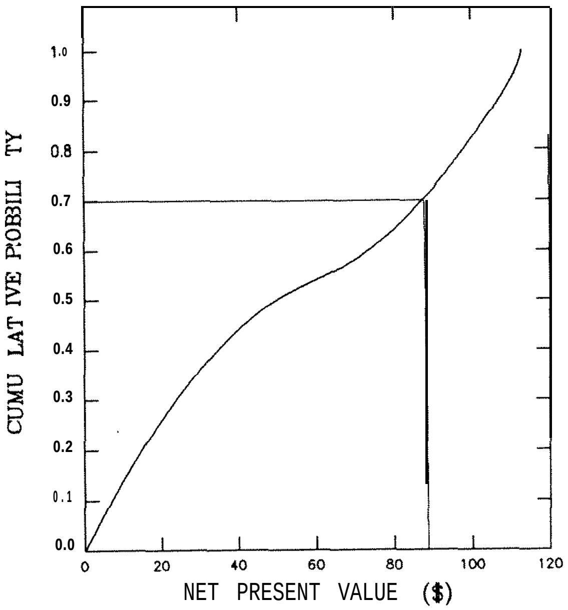
Decision Making under Risk

There are many ways to measure risk. Markowitz (1952) introduced the mean-variance rule. Under this rule the decision maker evaluates alternatives based on expected values and variances of the distributions of outcomes. Alternative A is preferred to alternative B if: (1) The expected value of A $>$ expected value of B and the variance of A $\leq$ variance of B, or; (2) The expected value of A = expected value of B and the variance of A < variance of B. Implicit in this analysis is the assumption that the decision maker is risk averse. For such individuals the prospect of losing a dollar of income decreases utility by more than the prospect of gaining a dollar increases utility.

The mean-variance rule cannot be used to select between A and B when mean and variance of A > mean and variance of B. Moreover, an assumption of this rule is that distributions of outcomes are normal. When distributions of outcomes are non-normal, other decision rules may be required.

An alternative to the mean-variance rule for decision making under risk is stochastic dominance analysis (SDA) (Quirk and Saposnik 1962, Hanoch and Levy 1969). SDA overcomes the normality limitation of the mean-variance rule, and in recent years has seen increasingly widespread use in the finance and agricultural economics literature. Applications reported in the forestry literature are limited. They include assessments of the economic rotation of a forest stand when the risk of fire is taken into consideration (Caulfield 1988) and for including risk into the decision of which species to plant on a given site (Caulfield et al., 1989). In the latter study, the volumes of 20-year-old loblolly (*Pinus taeda* L.), slash (*P. elliottii* Engelm.), and longleaf (*P. palustris* Mill.) pine were obtained for stands on wet, intermediate, and dry sites. The most efficient species-site selections were found by comparing the distributions of volume production using SDA.

Stochastic dominance analysis involves pairwise comparisons of cumulative probability functions of returns. The cumulative probability function gives the probability that an outcome will be $\leq$ any value. Figure 1 is an example of a cumulative probability function for some activity. It shows the probability that the outcome, in this case measured as net present value, will be $\leq$ any value. For example, 70 percent of the time the return is $\leq$ \$88. Another way of looking at it is that 30 percent of the time the return $>$ \$88.



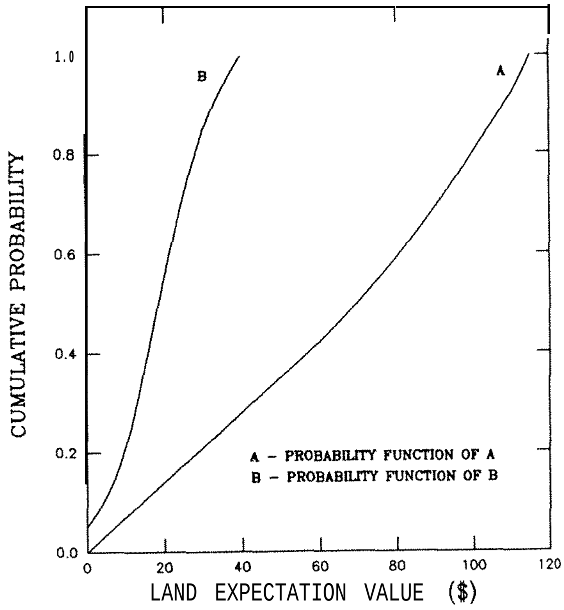


Figure 1. Au example of a cumulative probability function showing the probability that the net present value will be ≤ any value. 70 **percent of the time the net present value is $88 or less.**

Figure 2. For distribution A to dominate distribution B by 1st degree stochastic dominance, the probability function of A must lie to the right of B.

There are different degrees of stochastic dominance which are based on progressively stricter assumptions about a decision maker's preferences. First degree stochastic dominance assumes only that more is preferred to less. For alternative A to dominate B by 1st degree stochastic dominance, the cumulative probability function of A must lie to the right of B (Figure 2). An intuitive interpretation of this rule is that for any outcome, the probability that A will have a better outcome must be ≥ the probability that B will have a better outcome with at least one strict inequality.

When two cumulative probability functions intersect, they cannot dominate one another by 1st degree stochastic dominance. In this case, 2nd degree stochastic dominance may be used. This assumes that the decision maker prefers more to less and is risk averse. For alternative A to dominate B by 2nd degree stochastic dominance, the area between the cumulative probability functions when B > A must remain > the area between the curves when B < A (Fig. 3).

In both 1st and 2nd degree stochastic dominance analyses, pairwise comparisons of all alternatives are made. Any alternative that is not dominated in any of the pairwise comparisons is considered to be risk-efficient and is included in the efficient set.

Data

Operational data on the type of site preparation and survival rates following planting were obtained for 514 loblolly pine stands in the coastal plain of Alabama. Stands were established in the 1984-85, 1985-86, 1986-87, and 1987-88 planting seasons. Data from 397 stands which had received six different types of site preparation were selected for further analysis. These included chop followed by burning (CHOPB), chemical application only (CHEM), chemical application followed by burning (CHEMB), shear-rake-pile (SRP), shear-rake-pile-disk (SRPD), and shear-rake-pile-bed (SRPB).

Before decision making under risk can occur, a distribution of outcomes for each alternative is required. Operational data were used to provide the distributions of survival rates for the different site preparation methods. The focus of this paper is on demonstrating how risk can be incorporated into site preparation decisions and not on making site-specific site preparation recommendations. No attempt was made to group stands by site characteristics.

Table 1. Summary of survival rates following planting for stands receiving different site preparation treatments.

Site preparation	Number of stands	Mean survival rates	Variance
		(percent)	
CHOPB	72	61	229
CHEM	27	70	144
CHEMB	35	64	327
SRP	13	81	221
SRPD	124	83	209
SRPB	126	77	163

CHOPB: Chop followed by burning
CHEM: Chemical application only
CHEMB: Chemical application followed by burning
SRP: Shear-rake-pile
SRPD: Shear-rake-pile-disk
SRPB: Shear-rake-pile-bed

Summaries of data are provided in Figure 4 and Table 1. The overall mean survival rate was 74 percent. CHOPB had the lowest mean survival rate of 61 percent, and SRPD the highest at 83 percent. In addition to their low mean survival rates, CHOPB and CHEMB had the highest variances. CHEM had the lowest variance. Figure 4 is a box plot of the survival rate data. It is a useful way to graphically compare distributions of outcomes for different activities.

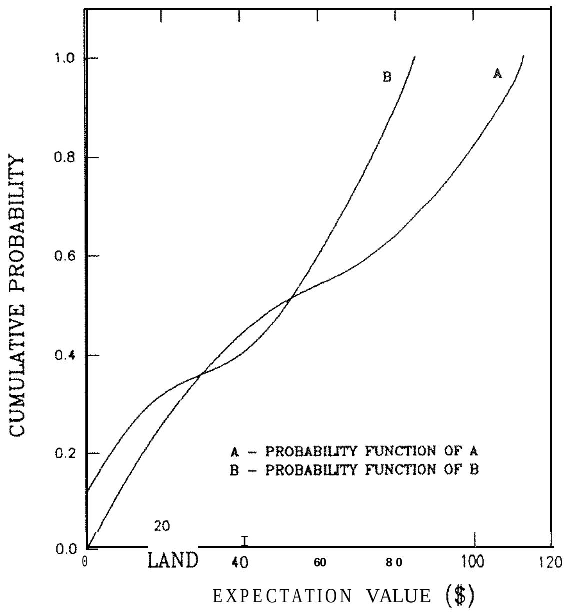
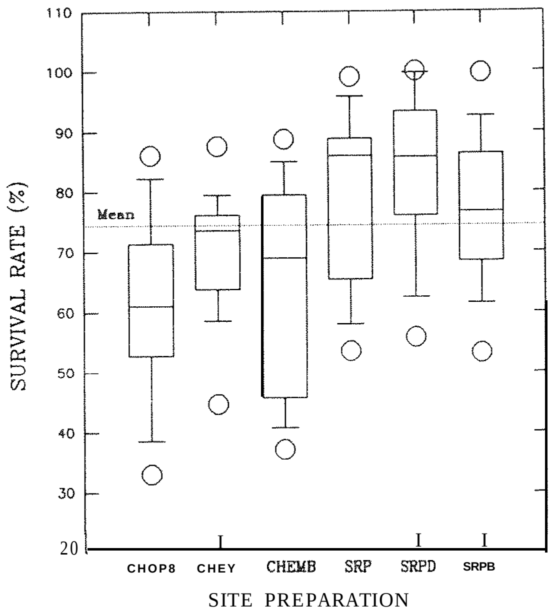


Figure 3. For distribution A to dominate B by 2nd degree stochastic dominance, area between curves when B > A must remain greater than the area between curves when B < A.



CHOPB: Chop followed by burning
CHEM : Chemical application only
CHEMB: Chemical application followed by burning
SRP : Shear-rake-pile
SRPD : Shear-rake-pile-disk
SRPB : Shear-rake-pile-bed

Figure 4. Box plots of survival rates following planting for stands receiving different site preparation treatments. Horizontal lines of each plot represent 10th, 25th, 50th, 75th, and 90th percentile points of data. Fifth and 95th percentiles are marked by circles above and below the 10 and 90 percent caps.

Based on mean survival rate alone, SRPD would be selected as the best site preparation alternative. Stochastic dominance analysis of survival rates revealed that the three site preparations which included shearing and raking (SRP, SRPD, SRPB) were in the efficient set by 1st and 2nd degree stochastic dominance.

Financial Return

Lower survival rates do not necessarily result in a lower financial return. Financial return measured by land expectation value (LEV) was, therefore, estimated for each of the 397 stands selected from the operational data. The first step was to calculate the LEVs for a range of survival rate and age combinations. Survival rate classes ranged from 20-100 percent and age classes from 22-35 years.

Value of the timber on the site for each survival rate and age combination was estimated as a residual value. Residual value was calculated as the delivered value of the wood less harvesting and transportation costs plus wood dealer profit.

Merchantable volume in cords/acre to a 4-inch inside bark diameter was estimated using the North Carolina State University managed pine plantation growth and yield simulator (Hafley et al., 1982). Pulpwood was considered to be the only product produced. Site index was 65 ft (base age 25), trees planted/ac was 700, and no thinning was prescribed. Implicit in the volume estimation is that mortality is randomly distributed and that growth is only influenced by the survival rate of planted seedlings.

A delivered price of $48/cord was used. This is the average price of southern yellow pine pulpwood reported for Alabama in TimberMart South from January 1983 to March 1989. Harvesting and transportation costs were calculated using the Auburn Harvest Analyzer (Tufts et al., 1985) which includes tree size as a variable. The number of trees per diameter class is one of the outputs of the growth and yield simulator used. Different harvesting costs were therefore obtained for each survival rate and age combination. Costs ranged from $28/cord for 100 percent survival at 22 years to $20/cord for 20 percent survival at age 35. Wood dealer profit was set at 15 percent.

Table 2. Total regeneration cost for different types of site preparation. Site preparation and planting costs are from Straka et al. (1989). Seedling costs were set at $24/thousand.

Site preparation method	Total regeneration cost
	($)
Chop followed by burning	128.20
Chemical application only	136.78
Chemical application followed by burning	146.84
Shear-rake-pile	175.80
Shear-rake-pile-disk	196.09
Shear-rake-pile-bed	210.13

Site preparation and planting costs were calculated from data reported by Straka et al. (1989). Seedling costs were $24/thousand. The total regeneration cost including site preparation, seedlings, and planting is given in Table 2. Costs range from $128/ac for CHOPB to $210/ac for SRPB.

For each survival rate and age combination the LEV was calculated using the following formula:

$$LEV = \frac{[V-T * (V-R)] - [R*(1+i)^A]}{(1+i)^A-1} - (1-T) * \frac{TA}{i}$$

where V = residual stumpage value; R = regeneration cost; A = age; TA = tax and administration cost of $5/ac; T = tax rate of 33 percent; and i = discount rate of 4 percent.

Examples of LEV over age for the least expensive site preparation method (CHOPB) are shown in Figure 5.

It is evident from Figure 5 that the rotation length that maximized LEV depended on the survival rate of planted seedlings. For example, a chopped and burned stand with a survival rate of 20 percent had a maximum LEV of $28 at age 32, whereas the same stand with 80 percent survival had a maximum LEV of $110 at age 26. Rotation age for each survival rate and site preparation method combination was selected as the age that maximized LEV.

Graphs of LEV over survival rate for the different site preparation treatments are shown in Figure 6. For any survival rate, financial return increased as site preparation costs decreased. One reason for this is the assumption that growth was only influenced by the survival rate of planted seedlings. The same relation may not hold when the effect of site preparation on growth is considered. Different growth rates caused by the type of soil disturbance and the impact on weed competition may result in different returns. The highest returns within any site preparation treatment were for stands with 75 percent survival, but the graphs are relatively flat between 50 and 100 percent survival.

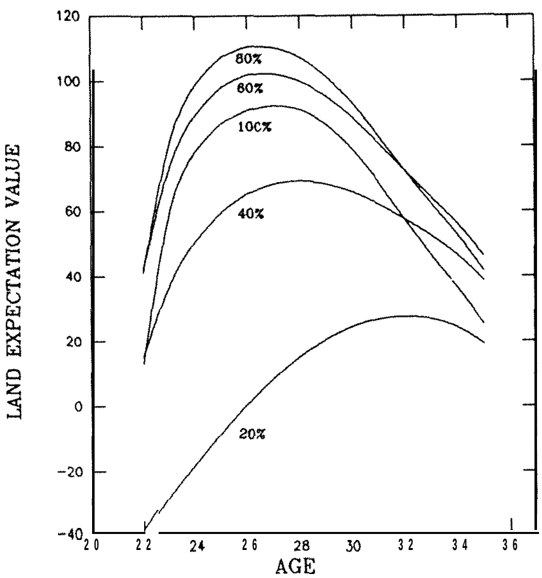


Figure 5. Land expectation value over age for different survival rates. Percentages below the lines are survival rates. Land expectation values are for stands with chop and bum site preparation.

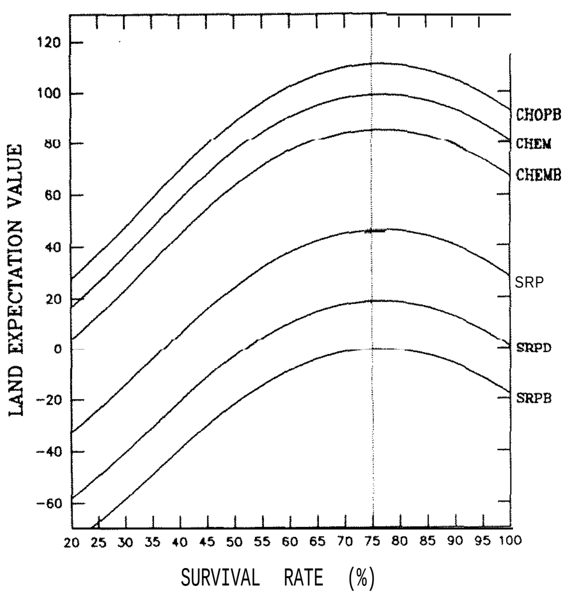


Figure 6. Maximum land expectation value over survival rate for stands receiving different site preparation treatments. (Refer to Fig. 4 for legend.)

Results and Discussion

Summaries of LEVs for stands included in the operational data set are shown in Table 3 and Figure 7. As expected, mean LEV decreased as site preparation costs increased.

Returns from the three most intensive site preparation treatments (SRP, SRPD, SRPB) had small variances, ranging from 30 to 77. The variances for the less-intensive site preparation treatments (CHOPB, CHEM, CHEMB) were much higher, ranging from 168 to 313.

Stochastic dominance analysis of LEVs revealed that CHOPB and CHEM were in the efficient set by 1st and 2nd degree stochastic dominance. Although CHOPB had a higher mean return than CHEM, variance of returns was much greater for CHOPB than for CHEM (Table 3).

Table 3. Summary of land expectation values for stands receiving different site preparation treatments.

Site preparation	Number of stands	Mean LEV	Variance	Highest degree of stochastic dominance
CHOPB	72	96	313	2nd
CHEM	27	93	168	2nd
CHEMB	35	71	299	
SRP	13	39	30	
SRPD	124	11	77	
SRPB	126	-6	46	

CHOPB: Chop followed by burning
CHEM: Chemical application only
CHEMB: Chemical application followed by burning
SRP: Shear-rake-pile
SRPD: Shear-rake-pile-disk
SRPB: Shear-rake-pile-bed

Results indicated that based on the assumptions of the analysis the efficiency of site preparation was dominated by cost. Higher survival rates and lower variance of returns for intensive site preparation were not sufficient on their own to overcome the lower regeneration costs of the less-intensive chop and chemical site preparations.

There are important caveats, however. First, conditions on the site may dictate the choice of site preparation method. For example, some chemically-prepared sites may have so much material remaining on-site that planting is not possible without burning. Wet sites may require bedding simply to ensure adequate growth rates. Second, the analysis assumes that growth is only influenced by survival rates of planted seedlings. Site preparation may influence growth through the type of soil disturbance and the impact on hardwood and herbaceous weed competition.

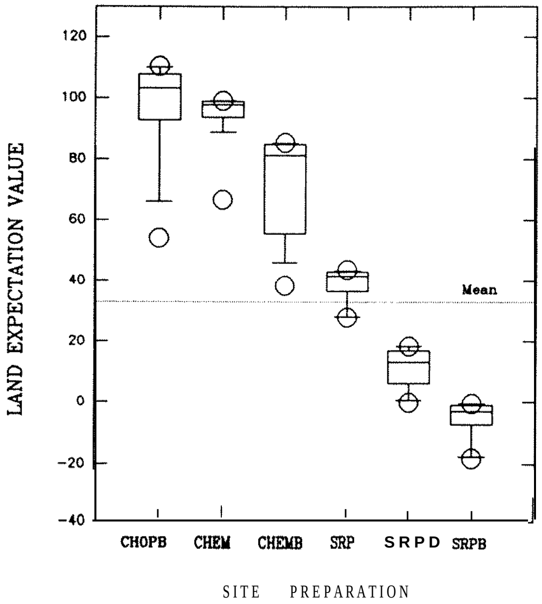


Figure 7. Box plots of land expectation values for stands receiving different site preparation treatments. Horizontal lines of each plot mark the 10th, 25th, 50th, 75th and 90th percentile points of the data. The 5th and 95th percentiles are marked by circles above and below **the 10 and** 90 **percent caps.** (Refer to Fig. 4 for legend.)

These caveats serve to highlight important areas which need to be considered when analyzing operational data to make site preparation decisions. Survival rate data need to be combined with site characteristic data so that the analyses can be based on a comparison of records from similar sites. Additionally, an estimate must be made of the direct effects of site preparation on volume production. Distribution of volume returns depends first on the distribution of survival rates. It is well known that density impacts volume production and current growth models account for this. However, for each survival rate the volume return also depends on the direct effect of the site preparation on growth rates. Different growth rates can be expected for stands with the same site characteristics and survival rates but different site preparation treatments.

Conclusion

This, paper demonstrates how risk can be included in site preparation decisions and how the decision may be different when distributions of financial returns are compared rather than relying on a comparison of mean survival rates. For the stands used in this study, the most costly site preparation methods which included shearing, raking and piling had higher survival rates than less intensive chemical and chop and burn methods. Analysis of the expected financial returns, however, placed chop followed by burning and chemical application only in the efficient set. Higher survival rates and lower variance of returns for intensive site preparation did not compensate for the higher cost of these treatments. Due to the assumptions made in the analysis the results should not be interpreted as blanket prescriptions.

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RESPONSE OF TEN-YEAR-OLD YELLOW-POPLAR TO RELEASE AND FERTILIZATION [1]

Ron A. Rathfon, James E. Johnson, and David A. Groeschl [2]

Abstract. A renewed interest in the cultivation of yellow-poplar (Liriodendron tulipifera L.) has recently developed as market conditions for the species have improved. Few published studies exist showing yellow-poplar growth response to both fertilization and crop tree release. The purpose of this study was to determine the response of lo-year-old yellow-poplar to crop-tree release and fertilization. The treatments were applied in June 1988 'in a completely randomized design with 12 replications of each treatment on each of two sites (slope site and cove site) . The fertilization treatment received 224, 261, and 243 kg/ha of N, P, and K, respectively. Crop trees were released by spraying the lower stem of competing trees within a 2-m radius with a 4 percent solution of triclopyr in diesel oil. Site differences influenced the way the crop trees responded to the treatments. On the slope site (poorer site), the crop trees responded positively to fertilization in stem diameter growth, height growth, and foliage nutrient concentrations after two growing seasons. Release elicited no growth response or possibly even a negative response after 2 years. On the cove site (better site), stem diameter growth and crown volume responded positively to release treatments but not to fertilization.

Introduction

Yellow-poplar (Liriodendron tulipifera L.) is an important hardwood species in the United States. It is a widely distributed tree species which comprises over 13 percent of the hardwood growing stock in the Appalachian Mountain region (Beck and Della-Bianca 1981). Its uses include short-fibered pulp used in low-grade wrapping paper, printing paper, and container board, hidden furniture parts, and core stock for veneer (Core 1978). Recently, efforts have been made to educate industry of the potential of yellow-poplar as a construction lumber (Muench 1989). Foresters appreciate yellow-poplar for its fast growth, good form, excellent natural self-pruning, and relative resistance to insect pests and disease (Fowells 1965). Yellow-poplar foliage is not a preferred food of the gypsy moth; yet another plus for this here-to-fore overlooked species (Gansner et al. 1987).

Yellow-poplar grows best on moist, nutrient-rich sites including coves and north aspects. On such sites, it can out-compete most other indigenous species, while on drier, less-fertile sites it succumbs to competition pressure from less-desirable chestnut oak (Quercus

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prinus L.) and red maple (Acer rubrum L.) sprouts, and often drops out of the stand.

Fertilization and crop-tree release are two silvicultural methods for improving the competitive position of yellow-poplar on sites where less-desirable species compete strongly with it. There are a number of studies addressing release or fertilization, but none that address the combination of treatments (Schomaker and Rudolph 1964, Finn and White 1966, Trimble 1973, Auchmoody and Smith 1977, Lof tis 1985, Lamson and Smith 1989). The objective of this study is to determine the growth response of yellow-poplar to factorial combinations of crop-tree release and fertilization treatments on two adjacent sites located in the Appalachian Mountains of southwest Virginia. Second-year responses are reported.

Methods

The study was located on two adjacent sites in the Appalachian Ridge and Valley physiographic provinces of southwest Virginia. One site was located on a north aspect side-slope above a minor drainage (slope site). The soil on this site was a loamy-skeletal, mixed, mesic Typic Dystrochrept. The other site was located on a ridge saddle in a slight cove-like depression (cove site). The soil on this site was a fine-loamy, mixed, mesic Typic Hapludult.

The current stands were created 11 years ago when a clearcut removed all standing trees. The previous stand was primarily a mixed-oak stand with some yellow-poplar present. The sites regenerated naturally. Most of the yellow-poplar stems were of seed origin, while other species such as the oaks and maples were of sprout and seed origin.

Stocking following 11 years of stand development was 15 and 18 m^2/ha of basal area for the slope and cove sites, respectively. On the slope site, yellow-poplar and chestnut oak each accounted for 2.3 m^2/ha, or 15 percent of the total basal area. The remainder of the stocking was made up of a mixture of Appalachian hardwood species, none of which individually accounted for more than 12 percent of the total basal area. On the cove site, 9.2 m^2/ha, or 51 percent of the stand stocking was composed of yellow-poplar, while chestnut oak only comprised 3.2 m^2/ha, or 18 percent of the total basal area. Again, the remainder of the stand stocking was comprised of a mixture of Appalachian hardwood species plus a small component of Virginia pine (Pinus virginiana Mill.), none of which individually accounted for more than 10 percent of the total stand basal area.

Release and fertilization treatments were randomly applied in factorial combinations to 48 individual crop trees on each of the two sites. Crop trees needed to be at least codominant, with no forks or evidence of mechanical or pathogen-related damage. Each treatment was replicated 12 times on each site. The treatments included: (1) control; (2) release; (3) fertilize; and (4) release plus fertilize.

The release treatment was applied using a basal application of a 4-percent solution of triclopyr in diesel oil to trees within a 2-m radius of the crop tree. The crowns of such target trees needed to at least extend into the upper half of the crop-tree crown. In addition, all grapevines within the vicinity of the crop trees were similarly treated. Only competing yellow-poplar were not treated with herbicide, but instead were removed mechanically with a hand ax. This was to preclude damage to the crop trees through translocation of herbicide across root grafts.

Fertilizer was broadcast in a 2-m radius band around the crop tree. A complete fertilizer was used to apply 224, 291, and 243 kg/ha of elemental nitrogen (N), phosphorus (P), and potassium (K), respectively.

The dbh and total height were measured at the time of treatment (mid-June) and again after one and two growing seasons. Crown diameter and height-to-live crown were measured after the first and second growing seasons. A crown volume index (hereafter referred to as crown volume, or CV) was calculated using the following formula:

$$CV = \pi r^2 H/2.$$

Foliage was collected from the crop trees in mid-August of the first and second growing seasons. Only sun leaves from the upper one-third of the crown were sampled. The foliage was oven-dried at 65°C and ground in a Wiley mill to pass a 1 mm sieve. Total Kjeldahl nitrogen of the foliage was determined by block digestion (Bremner and Mulvaney 1982) and subsequent analysis using the ammonia salicylate colorimetric technique on a Technicon Autoanalyzer. Total P and K were determined from dry-ashed samples using inductively coupled plasma spectrometry (ICP). Soil samples were collected prior to treatment from each site and soil pits were dug on each site to provide characterization data (Table 1).

Table 1. Comparison of site characteristics of the yellow-poplar crop-tree release and fertilization study.

Site	Depth to C hor.	Depth to bedrock	Litter depth	O.C.[1]	Surface 15-cm soil properties Text.	pH	N[2]	P[3]	K[3]
	(cm)	(cm)	(cm)	(percent)			---(kg/ha)---		
Slope site (poorer)	48	79	3	1.5	loam	4.8	69.6	3.1	74.0
Cove site (better)	79	140+	8	1.7	loam	4.6	36.4	2.4	60.6

[1] Organic carbon as percent by weight.
[2] Anaerobically-mineralizable nitrogen (Keeney 1982).
[3] Dilute double-acid extraction (Olsen and Sommers 1982).

The tree measurement data were analyzed as a two-way factorial design using analysis of covariance, with 'pretreatment data as the covariate. Where covariates were nonsignificant or nonapplicable (as with nutrient data), analysis of variance was used.

Results And Discussion

Site Differences

Site differences seemed to influence the manner of response of the yellow-poplar crop trees to the various treatments. There were readily apparent differences between the two stands. The mean pretreatment dbh and height of the crop trees on the slope site were 5.4 cm and 7.6 m, respectively, while on the cove site they were 8.1 cm and 9.7 m, respectively (Table 2). In addition to overall stocking level differences (slope = 15 m^2/ha, cove = 18 m^2/ha), there were also differences in species composition. Yellow-poplar dominated the cove site, accounting for 51 percent of the basal area. On the slope site, yellow-poplar accounted for only 15 percent of the stand basal area (Table 2).

Table 2. Comparison of stand characteristics of the yellow-poplar crop-tree release and fertilization study.

Site	Pretreatment Crop dbh	Pretreatment Tree mean height	Total basal area	Species Composition[1] YP	co	SW
	(cm)	(m)	(m^2/ha)	(m^2/ha)		
Slope site (poorer)	5.4	7.6	15.2	2.3	2.3	1.8
Cove site (better)	8.1	9.7	17.9	4.6	3.2	1.8

[1] The three most abundant species in terms of basal area/ha:
YP = yellow-poplar (Liriodendron tulipifera),
co = chestnut oak (Quercus prinus),
SW = sourwood (Oxydendrum arboreum).

Soil descriptions on each of the two sites may explain these stand differences (Table 1). The slope site was characterized by a relatively shallow soil. Depth to the C horizon was located within 51 cm of the soil surface and depth to bedrock was within 79 cm of the soil surface. The forest floor litter layer was very thin (3 cm).

The cove site had a relatively deep soil, with depth to the C horizon 79 cm from the soil surface. Depth to bedrock was greater than 140 cm from the soil surface. This site also had a fairly thick forest floor litter layer (8 cm) with an accompanying preponderance of fine root growth. Although anaerobically-mineralizable N and extractable P and cations were available in greater abundance in the surface 15 cm of the less-weathered inceptisol of the slope site, the larger total rooting volume of the more-highly weathered ultisol on the cove site provided markedly-improved nutrient and moisture conditions for crop tree growth.

Slope Site

On the slope site, stem diameter growth and height growth over the 2-year period following treatment were 38 percent and 25 percent greater, respectively, for fertilized trees than for unfertilized trees (Table 3). Mean dbh and mean total tree height after 2 years were also significantly greater for fertilized (6.5 cm dbh and 8.6 m) versus unfertilized trees (6.2 cm dbh and 8.4 m). Crown volume and crown volume growth were not significantly higher for the fertilized trees. Foliage nutrient concentrations for the slope site trees responded positively to fertilization (Table 4) for all three nutrients applied.

Table 3. Slope site second year growth response of yellow-poplar to crop-tree release and fertilization.

Treatment	Dbh[1]	Diameter increment'	Ht[1]	Height increment[2]	Crown volume	Crown volume increment
	(cm)	(cm)	(m)	(m)	(m^3)	(m^3)
Release :						
No release	6.4	1.0	8.6	1.0	9.8	3.6
Release	6.3	0.9	8.4	0.8	11.0	4.7
Fertilization:						
No fert	6.2	0.8	8.4	0.8	10.0	3.8
Fert	6.5*	1.1*	8.6*	1.0*	10.8	4.5

* Significant at α = 0.05.

[1] Means adjusted for pretreatment data and analyzed using analysis of covariance.

[2] Release x fertilization interaction significant at α = 0.07. Except where indicated, all interactions are nonsignificant.

There were no significant main effect responses to release, and indeed the diameters and heights seemed to respond negatively (Table 3). This lack of response, or negative response to release, corroborates several other yellow-poplar release studies which show a similar response immediately following thinning (Trimble 1973, Lamson and Smith 1989). The released yellow-poplar did not show significant increases in crown volume and crown volume growth over non-released trees.

Table 4. Slope site response of yellow-poplar foliage nutrient concentrations to crop-tree release and fertilization- 1989 results.

Treatment	Foliage nutrients N	P	K
	---------- (percent) ----------		
Release :			
No release	2.43	0.211	1.140
Release	2.34	0.200	0.995*
Fertilization:			
No fertilization	2.18	0.175	0.984
Fertilization	2.59**	0.236**	1.151*

* Significant at α = 0.05.
** Significant at α = 0.01.

There was an interaction in height growth between the release and fertilization treatments detected at the α = 0.07 level of significance (Fig. 1). This interaction shows not only a lack of response to release, but shows the release treatment negatively influencing height growth where fertilizer is applied in combination with release; i.e., even though fertilization alone effected a positive growth response, it could not overcome the negative influence of the release treatment on height growth 2 years following treatment application. "Thinning shock," a condition of physiological stress caused by sudden, excessive exposure to sunlight following thinning treatments, may have occurred in this instance (Powles and Bjorkman 1982, Donner and Running 1986).

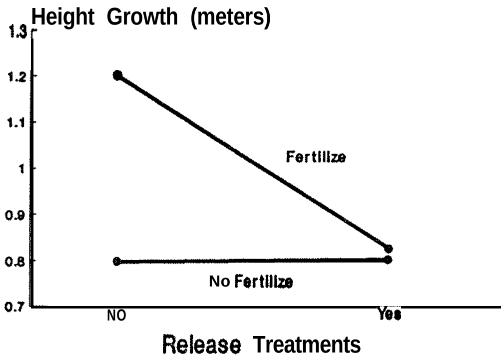

Figure 1. Slope site release x fertilization interaction of the height data.

Cove Site

Only stem diameter and crown volume exhibited significant responses to treatment on the cove site. The dbh, stem diameter growth, crown volume, and crown volume growth all responded positively to the release treatment (Table 5), as compared with the fertilization treatment response seen on the slope site. There were no tree growth responses to fertilization on the cove site (Table 5). Nor were there significant differences in foliage concentrations between treatments for any of the nutrients (Table 6).

Table 5. Cove site second-year growth response of yellow-poplar to release and fertilization.

Treatment	Dbh[1]	Diameter increment[1]	Ht[1]	Height increment	Crown volume[1]	Crown volume increment
	(cm)	(cm)	(m)	(m)	(m^3)	(m^3)
Release :						
No release	9.7	1.5	11.0	1.3	20.0	3.7
Release	9.9*	1.7*	11.0	1.2	28.3*	11.9*
Fertilization:						
No fert	9.8	1.6	11.0	1.3	24.8	a.4
Fert	9.8	1.6	11.0	1.3	23.6	6.5

* Significant at $\alpha = 0.05$.
[1] Means adjusted for pretreatment data and analyzed using analysis of covariance. No significant interactions.

Table 6. Cove site response of yellow-poplar foliage nutrient concentrations to crop-tree release and fertilization- 1989 results.

Treatment	Foliage nutrients' N	P	K
	------------ (percent)	------------	
Release :			
No release	2.31	0.189	0.974
Release	2.44	0.185	0.862
Fertilization:			
No fert	2.33	0.174	0.899
Fert	2.42	0.198	0.937

[1] No statistically-significant differences.

Although responses to release were small (though significant) for diameter and nonexistent for height on the cove site, crown volume growth was over three times greater for released trees than for non-released trees. As with the slope site, there seemed to be a delayed response to release.

Some researchers attribute this delayed response to a reallocation of photosynthates from height and stem-diameter growth to crown expansion (Lamson and Smith 1989; Ginn et al., in press). Thus the crown expansion observed on this site may precede and ultimately result in increases in stem diameter growth and tree volume growth.

Tree height and height growth is generally believed to be nonresponsive to release treatments (Smith 1962). This is confirmed in more recent studies involving yellow-poplar (Lamson and Smith 1989) and may also partially explain the lack of height-growth response to release on both sites.

The previously enumerated differences between the two sites account not only for overall stand differences, but they may also help to explain the differences in tree growth response to the experimental treatments between the sites. The apparently nutrient-deficient slope-site crop trees responded positively to fertilization, while on the already-nutrient-enriched cove site the crop trees displayed no such response. Baker and Blackmon (1977), Buckner and Maki (1977), and Francis (1977) all report greater yellow-poplar growth response to fertilization on the poorest sites of their respective studies. Yellow-poplar fertilization studies located on nutrient/moisture sufficient sites indicate that heavy fertilization applications (335 - 900 kg N/ha) may be necessary to elicit significant growth responses . The lack of foliage nutrient concentration response to fertilization in cove-site crop trees further suggests that yellow-poplar may not respond to modest fertilizer inputs on such "good" sites.

Because of better site conditions, stand development on the cove site was more advanced compared with stand development on the slope site. Thus the trees on the cove site were experiencing more intense competition for sunlight. This condition, along with the inherent nutrient- and moisture-rich conditions of the cove site, provided for a more immediate response to release than was possible on the nutrient- and moisture-depauperate slope site.

Conclusions

Site conditions seemed to influence the response of yellow-poplar to crop-tree release and fertilization. On the impoverished slope site, the crop trees responded positively to fertilization, but did not respond at all, or possibly responded negatively, to release. On the "good" cove site, the crop trees did not respond to fertilization, but did respond positively to release. Although many of these responses were statistically significant, it is difficult to ascertain their economic importance after only 2 years. Provided that response to these treatments is economically justifiable, it is evident that site must be considered when contemplating the employment of crop-tree release and fertilization in the silviculture of yellow-poplar.

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RELEASING FOUR-YEAR-OLD PINES IN MIXED SHORTLEAF-HARDWOOD STANDS [1]

F. Thomas Lloyd, David L. White, James A. Abercrombie, Jr., and Thomas A. Waldrop[2]

Abstract. At age 4, planted shortleaf pines (*Pinus echinata* Mill.) were released in pine-hardwood mixtures on medium quality upland sites. Over the next 2 years, height and diameter growth of pines and height growth of hardwoods were observed. Height growth estimates indicate that the pines are successfully establishing themselves in the overstory without the help of release. At the same time, reducing hardwood competition did enhance pine diameter growth. Specifically, the spring felling of competing hardwoods increased 2-year pine diameter growth by 17 percent over the no-treatment control, and a winter felling and herbicide treatment increased diameter growth by 22 percent.

Introduction

Deliberate regeneration of pine-hardwood mixtures is a new idea that shows promise in the Southern Appalachians and Piedmont Plateau of the Southeastern United States (Waldrop and others 1989). On upland sites of medium quality where hardwoods have become established, intensive site preparation and pine plantation management can be prohibitively expensive for many forest landowners. A regeneration system called "fell-and-burn" (Abercrombie and Sims 1986, Phillips and Abercrombie 1987) has been developed and extensively used in the mountain and foothills region of South Carolina. If management objectives include hardwoods for wildlife, firewood, and aesthetic benefits as well as pines for timber production, then stands regenerated with this system will develop satisfactorily with no further treatment. However, some owners are interested in increasing pine volume and would like to know how well the pines will respond to release from hardwood competition. The long-term objectives of our study are to compare pine survival and growth in mixed pine-hardwood stands in which pines are and are not released.

The pine-hardwood stands used in this study are products of the fell-and-burn system developed and extensively used on the Andrew Pickens District of the Sumter National Forest in the mountain and foothills region of South Carolina. The sites on which this system is practiced are generally south- to southwest-facing slopes with site indices for oaks of 55 to 65 ft at age 50. The system consists of a commercial clearcut, spring felling of the residual stems, a summer fire to knock back the coppice regrowth and reduce logging slash, and interplanting of shortleaf pine (*Pinus echinata* Mill.) on sites with elevations

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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above 1000 ft. The summer burning is done over a wet forest floor so as not to consume the 3- to 6-inch root mat (0, and O_i layers) characteristically found on the sites. This organic layer protects against soil erosion and helps facilitate high survival of planted shortleaf pines by improving soil moisture in the rooting zone. With a high survival rate, the 10-ft by 10-ft spacing called for on the Andrew Pickens district yields a large, uniform pine component in the developing stands.

Xethods

The three stands selected for study were harvested during the 1980-81 dormant season. Residual stems taller than 6 ft were felled after leaf-out in the spring of 1981. The sites were summer-burned in 1981 and planted with graded, l-year-old shortleaf pine seedlings during the 1981-82 dormant season. Two types of plots were laid out during the 1985-86 dormant season (after four pine growing seasons). First, in each stand six 52.5-ft by 82-ft plots (hereafter called treatment plots) were laid out in a two plot by three plot pattern. Plots were separated with 16.4-ft buffer strips. superimposed on the treatment plots were nine 9.8-ft by 121.4-ft strip plots (hereafter called initial inventory plots) whose long dimension was oriented across contiguous treatment plot pairs. The initial inventory plots were used to estimate average heights and stem densi ties per acre by species before treatments were imposed.

After the initial inventory, all planted pines within each of the 18 treatment plots were identified with a numbered tag and basal diameter l-ft above the ground and total height were measured. Before the treatments were installed, all woody stems within 5 ft of each tagged crop pine were counted, identified by species, and measured for total height (only the tallest stem in each sprout clump) and distance (to the nearest f t) from the crop pine. Inclusion within the 5-ft radius was based on the location of the stump for sprout clumps or the stem groundline location for advanced regeneration, not the location of the crown projection.

Three treatments were randomly assigned (three treatments to six plots at three locations) and installed during the 1985-86 dormant season (when the pines were 4-years-old) following both the strip inventories and the hardwood stem measurements around the crop trees. The treatments were: (1) control (no release), (2) spring felling of competing hardwoods in a specified radius of each tagged pine, and (3) winter felling in the same way as the spring felling followed by application of a herbicide to all stumps. The herbicide was Garlon 3A™ prepared as a mixture of one part Garlon to two parts water applied to stumps in late winter (February 2 to March 31) within 7 days of the stem felling. The study plan called for felling all hardwoods within 5 ft of each crop pine. However, research technicians were not available when treatments were to be installed, so a commercial contractor was used instead. The practice of the commercial operator was to ocularly estimate distance. A follow-up check showed clearing radii generally fell between 3 and 5 f t . The treatment plots were remeasured 2 years after treatment in the same way as before treatment.

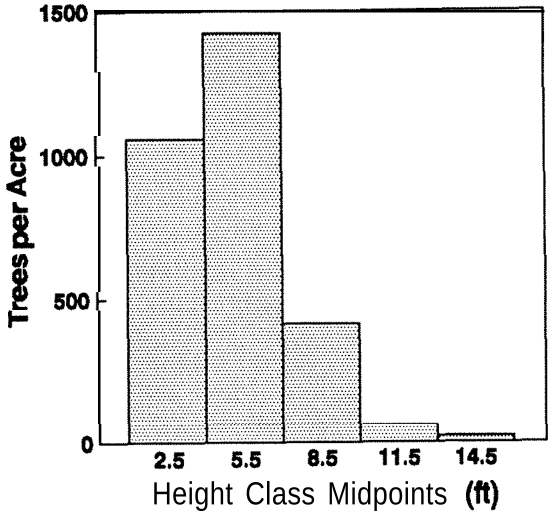

Figure 1. Hardwood height frequency distribution at age 4 (inventory plots).

Results And Discussion

At the beginning of the study, the average height of pines exceeded the average heights of oaks, "fast starter" hardwoods, and other woody stems (Table 1). However, the frequency distribution of hardwood heights in Figure 1 shows that the average hardwood heights in Table 1 are misleading in that they are made up of large numbers of small stems. The size distribution shows the presence of approximately 500 hardwood stems that were 8.5 to 14.5 ft tall. The weighted average height of these larger hardwoods is 9.1 ft. In other words, a fairly dense stand of large hardwoods averaged 2.28 ft of height growth per year prior to treatment installation, while pines averaged 2.13 ft per year during the same period.

Table 1. Estimated number of stems per acre and mean stem height (only the tallest stem when in sprout clumps) from inventory of strip-plots prior to treatment.

Species group	Number of stems per acre	Mean stem height
	--- (number) ---	--(ft)--
Planted shortleaf	349	8.5
oaks	730 [b]	5.6 [d]
Fast starters[a]	203 [b]	7.5 [d]
All other woody stems	2033 [b,c]	4.6 [d]
Total	3317	

[a] Includes black cherry, red maple, and sourwood.
[b] Total number of hardwood sprouts and seedlings.
[c] Includes volunteer shortleaf pine.
[d] Weighted average height is 5.0 ft using the number of stems for the three hardwood groups.

Remeasurement of treatment plots during the 1987-88 dormant season provides data on growth of pines and hardwoods near them (Table 2). From age

4 through age 6, pines maintained their height growth, while experiencing only 0.3 percent mortality. Average annual height increment for pines before treatment (using all plots) was 2.16 ft/yr, while annual increment averaged 2.25 ft/yr between ages 4 and 6 on both the control plots and the released plots. This outcome would be unlikely if the pines were being overtopped by the hardwoods.

Table 2. Average pretreatment (1985-86 dormant season) and post-treatment (1987–88 dormant season) heights for crop pines and three hardwood subsets.

	Pretreatment- age 4			Post-treatment- age 6		
	Pine	Hardwood		Pine	Hardwood	
		tallest within:			tallest within:	
Treatments		3 ft	5 ft		3 ft	5 ft
	(ft)					
Control	8.9	6.3	9.0	13.4	8.1	10.7
Spring fell	8.6	5.8	7.9	13.0	5.3	6.9[a]
Winter fell -herbicide	8.4	5.7	8.1	13.0	4.4	6.2[a]

[a] Some trees in these average heights were not felled at the time of treatment.

The hardwood height data support the assertion that the unreleased pines are successfully competing with the hardwoods. We arbitrarily defined a "tallest" subset of hardwoods as those on the O.l-ac treatment plots (43 trees) whose stem count per acre equaled the planted pine density of 436 seedlings/ac. Table 2 presents the average height of these tallest 43 hardwoods on each treatment plot within a 3-ft radius and a 5-ft radius of the crop pines. At age 4, the tallest hardwoods within 3 f t of pines averaged 2.40 ft shorter across all treatments than the tallest hardwoods within the larger radius (these data were taken before the felling treatments were installed). The trend was similar (2.70 ft) at age 6 (control plots only).

Another perspective on relative competition is gained by comparing average annual height increment of hardwoods on the control plots before age 4, when the hardwoods were more free to grow, with growth after age 4 (Table 2). Prior to age 4, the tallest hardwoods within 5 ft of pines on the controls averaged 2.25 ft/yr, but their height growth between age 4 and 6 slowed to 0.85 ft/yr. This slowing occurred while pine height growth was steady to slightly increasing for the pines. There are other possible explanations for the reduced hardwood growth, like decreasing sprout vigor, but increasing competition is also a plausible explanation. Given the size of the pines, much of this competition could be from them. Any of the above points, alone, is not conclusive. Taken together, however, the results indicate that a vigorous pine component will be established in the developing overstory without release.

Height growth and diameter growth of pines in the 2 years after treatment were analyzed for differences between treatments as a Randomized Complete Block (RCB) design. Analyses of variance on height growth showed no variance component due to locations (no differences in height growth between locations) and no significant differences between treatments. We expect location effects on height to eventually be significant because of site quality differences, but this variation is removed from the statistical comparison by the RCB design. The lack of treatment effect on height growth was expected.

Table 3 shows diameter growth between ages 4 and 6. Both the location variance component and the test statistic for treatments were statistically significant. The location effect is probably caused by differences in stand density, but we did not attempt to verify that possibility. Two-year pine diameter growth for the spring felling release treatment was 17 percent higher than the control (Table 3). Felling in the winter and spraying with herbicide added 5 percent more growth over the spring felling treatment. Both increases were statistically significant.

Table 3. Average basal diameter (1 ft aboveground) increment of the crop pines between age 4 and 6.

Treatments	2-year diameter increment	Percent increase over control
	-----(inches)-----	---(percent)----
Control	0.92	
Spring fell	1.08	17
Winter fell-herbicide	1.12	22

Conclusions

There is strong evidence from these short-term results that the pines in these mixed stands do not need to be released to remain competitive. The hardwoods are not likely to shade them out. At the same time, pine diameter growth responded strongly to reduced competition. It remains to be seen how long the diameter response will be maintained. Understanding these long-term changes will require measurement of growth of all woody vegetation on the plots, not just the hardwoods within 5 ft of the crop pines.

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GRANULAR IMAZAPYR AND HEXAZINONE RATE STUDY-EFFICACYOF COMPETITION CONTROL AND EFFECTS ON PINE GROWTH [1]

Robert W. Loveless and Henry H. Page, Jr. [2]

Abstract. The efficacy of varying rates of granular formulations of imazapyr (Arsenal™ 5G) and hexazinone (Pronone™ 10G) for hardwood competition control in a 3-year-old loblolly (*Pinus taeda* L.) pine plantation was examined. The study is located in Butler County , Alabama. Treatments were completely randomized and replicated four times. Treatments included Arsenal 5G at 0.375 lb ae/ac and 0.5 lb ae/ac, Pronone™ 10G at 1.0 lb ai/ac and an untreated check. One year after treatment, both imazapyr treatments had significantly reduced hardwood stems/acre but had also significantly reduced total pine height growth. Hexazinone had reduced the total number of hardwood stems/ac but plot variation did not allow the reduction to be declared significant. There was no significant difference in the pine height growth between the hexazinone treatment and the untreated check.

Introduction

Arsenal™ is an imidazolinone compound developed by American Cyanamid in 1981 for nonselective pre- and post-emergent weed, brush, and hardwood control (Thomson 1986). Several studies were initiated in the early to mid-1980s examining its efficacy in pine release work (Minogue 1985, Minogue 1986, Minogue and Creighton 1987). Most of these studies utilized liquid formulations and rates that are now recognized as being excessively high for conifer release work. The labeled rate for pine release using the liquid formulation of Arsenal is now from ½ to 1-lb ae/ac. In the spring of 1989, Jefferson Smurfit Corporation/Container Corporation of America (JSC/CCA) was approached by American Cyanamid about testing a solid formulation of Arsenal as a 5 percent active granule on a limes tone carrier . JSC/CCA decided to install a release study in a young pine plantation in Butler County, Alabama. The Arsenal treatments were tested at two different rates and were compared to a solid formulation of hexazinone (Pronone™ 10G) and to an untreated check.

Objectives

Objectives of this study were to: (1) evaluate the efficacy of hardwood control at different rates of a solid formulation of imazapyr as a 5 percent ae granule and hexazinone as a 10 percent ai granule; (2) evaluate the effects of the treatments on pine growth response; and (3) determine if these treatments might offer the potential for viable hardwood release treatments in young stands of pine under the age of 5.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Methods

The site is located on JSC/CCA land in Butler County, Alabama, approximately 8 miles east of Greenville. A Soil Conservation Service map (Parks, unpublished data) of the area indicates an Orangeburg soil with slopes varying from O-8 percent. The Orangeburg series consists of deep, well-drained, moderately permeable soils on ridges and side slopes. These are sandy loam soils with a sandy clay loam subsoil starting between 14 and 20 inches and continuing to a depth of 60 to 72 inches. The lower part of the pedon greater than 40 inches in depth may develop into a sandy clay.

The stand of pines at the time of treatment was entering its third growing season. The area had been sheared, raked, and disked in 1986 and planted in the winter of 1986-87. Pine stocking at the time of initiation of the study averaged 590 stems/ac. Initial hardwood stocking from seedlings and sprouts was 612 trees/ac. Clumps of hardwood stump sprouts were tallied as one root-stock.

The treatments were Arsenal 5G at 0.375 lb ae/ac, Arsenal 5G at 0.5 lb ae/ac, Pronone 10G at 1.0 lb ai/ac, and an untreated check. The study consisted of four replications on 1/10-ac[2] treatment plots in a completely randomized design. All treatment plots were separated from each other by a one chain buffer area. A .025-ac pine measurement plot was centered within each treatment plot.

Herbicide applications were made on May 24, 1989, using a hand-held cyclone spreader. The product was weighed out for each individual plot and applied as uniformly as possible. Arsenal 5G is a much denser product, 105.6 g/100 cc, than the Pronone 10G, 61.64 g/100 cc, and is a smaller granule. The amount of product per plot, especially the Arsenal, proved somewhat difficult to distribute evenly. Rainfall occurred on three different occasions over the 2 weeks after treatment, totaling over 2 inches.

All pines within the measurement plot were tallied for initial heights, heights 3 months after treatment, and heights 13 months after treatment. At each corner of the pine measurement plot, a 7-ft radius circular hardwood tally plot was taken and hardwoods were tallied by species and number of stems. Hardwood measurements were taken on the same schedule as that used for the pine.

Analysis And Results

Analysis of covariance was employed to test for significant differences in mean pine heights and hardwood rootstock densities between the four treatments. Initial pine height and initial hardwood stems per acre were used as the respective covariates. The analysis of covariance revealed the presence of significant (α = 0.10) differences between the mean post-treatment pine heights among treatments (Fig. 1.). Both the low (0.375 lb ae/ac) and the high (0.5 lb ae/ac) rates of granular imazapyr produced mean pine heights that were significantly less than both the untreated check and the granular hexazinone treatment. After adjustment for pretreatment height, the low rate of imazapyr averaged 6.34 ft in height and the high rate averaged 6.44 ft 1 year after treatment. The granular hexazinone

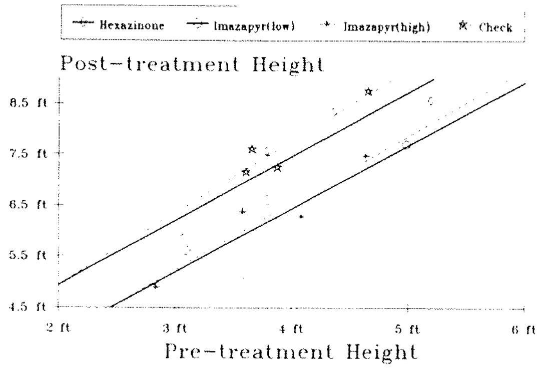

Figure 1. Pre- vs. Post-treatment pine heights.

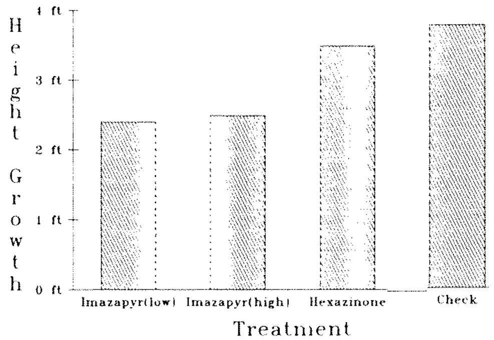

Figure 2. Marginal height growth of **pine 1 year after treatment.**

treatment had a mean height of 7.36 ft and the untreated check averaged 7.66 ft. The latter two treatments did not differ significantly. Figure 2 shows the observed marginal height growth differences by treatment. All assumptions necessary for analysis of covariance were satisfied and there was no evidence of bias due to site variability.

The hardwood rootstock density data were analyzed separately for each of the four most frequently occurring species and the remainder of the species were grouped as "miscellaneous" species. The four most common species, in order of occurrence, were sweetgum (Liquidambar styraciflua L.), black cherry (Prunus serotina Ehrh.), water and willow oaks (Quercus nigra L. and Q. phellos L) , and hawthorn (Crataegus spp.) . Once again, analysis of covariance was employed to adjust for unequal numbers of rootstocks among plots prior to treatment. An identical analysis of the miscellaneous rootstock counts revealed no differences between treatments. Swee tgum was the only species for which significant (α = 0.10) treatment differences were found (Fig. 3). All three chemical treatments had fewer sweetgum rootstocks than the check. Check plots had an adjusted mean of 286 sweetgum stems/ac as compared with 152, 92 and 70 stems/ac of sweetgum on the high imazapyr, low imazapyr, and hexazinone treatments, respectively. None of the chemical treatments differed significantly from each other in their degree of sweetgum control.

Pretreatment minus post-treatment stem/ac differences were calculated for all five 'species groups on each of the hardwood measurement subplots. T-tests were performed by treatment to test the null hypothesis that the mean difference was equal to zero. Table 1 shows the results of these T-tests on the total hardwood stems/ac. Water and willow oak, black cherry, and the miscellaneous species (Fig. 4, 5, 6) showed mixed responses in the change in number of stems/acre. None of these individual species responses could be declared significant. Significant (α = 0.10) post-treatment reductions in hawthorn stems/ac were found for both of the imazapyr treatments, but a marginally significant ($Pr>|T|=$ 0.1038) decrease was also observed on the check plots (Fig. 7). There were no hawthorns present on the hexazinone plots. The low rate of imazapyr and the hexazinone treatments both produced significant (α = 0.10) decreases in sweetgurn stems/ac 1 year after application. The low rate of imazapyr reduced observed sweetgum

Table 1. Results of T-tests under the null hypothesis that treatment means equal 0 for total hardwood rootstock density data.

Treatment	N	Variable	Mean	T	Prob > |T|
(lb ae/ac)					
Arsenal (0.375)	16	SPA1[1]	565.93	3.935	0.0013
		SPA2[2]	389.06	3.379	0.0041
		SPADIF[3]	176.87	2.076	0.0555
Arsenal (0.5)	16	SPA1	459.81	3.153	0.0066
		SPA2	282.93	2.582	0.0208
		SPADIF	176.87	2.439	0.0276
Control	16	SPA1	725.06	3.510	0.0032
		SPA2	689.56	3.024	0.0085
		SPADIF	35.50	0.334	0.7425
Pronone (1.0)	16	SPA1	672.00	3.135	0.0068
		SPA2	371.37	2.835	0.0125
		SPADIF	300.62	1.349	0.1973

[1] SPA = initial stems/ac
[2] SPA2 = stems/ac post-treatment, 1 year later
[3] SPADIF = SPA1 - SPA2

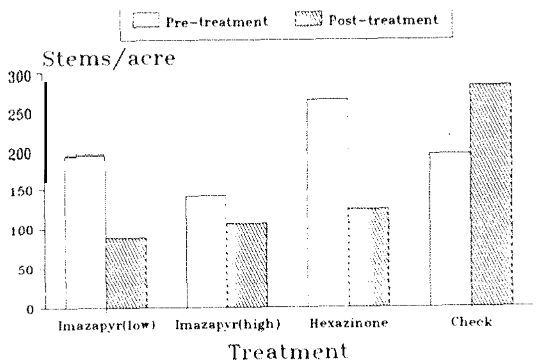

Figure 3. Pre- and post-treatment sweetgum stems/ac.

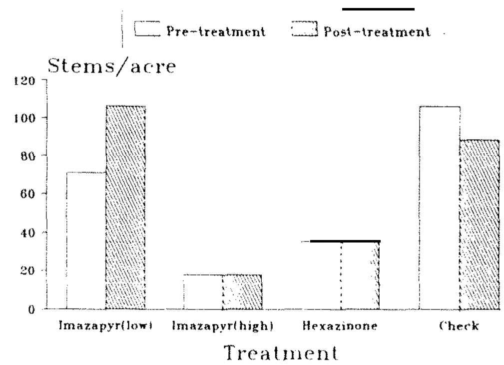

Figure 4. Pre- and post-treatment water and willow oak stems/ac.

densities from 195-88 stems/ac, while hexazinone reduced sweetgum densities from 265-124 stems/ac. Sweetgum densities decreased by 35 stems/ac on the high imazapyr plots and increased from 195-285 stems/ac on the check plots,

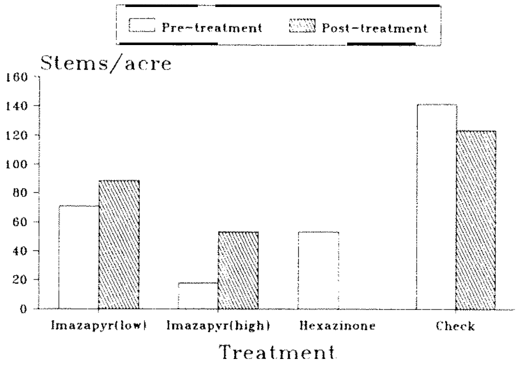

Figure 5. Pre- and post-treatment black cherry stems/ac.

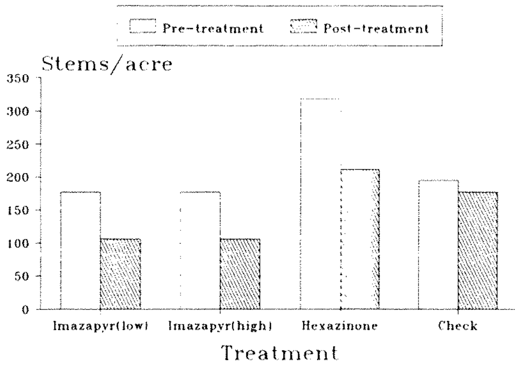

Figure 6. Pre- and post-treatment miscellaneous hardwood s tems/ac.

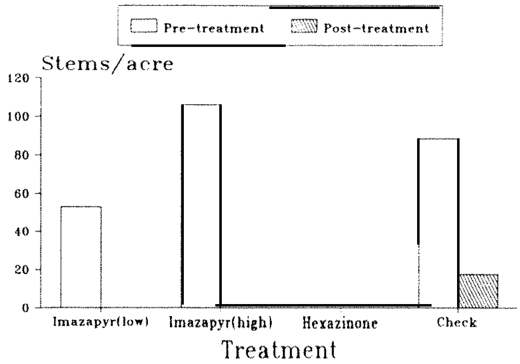

Figure 7. Pre- and post-treatment hawthome stems/ac.

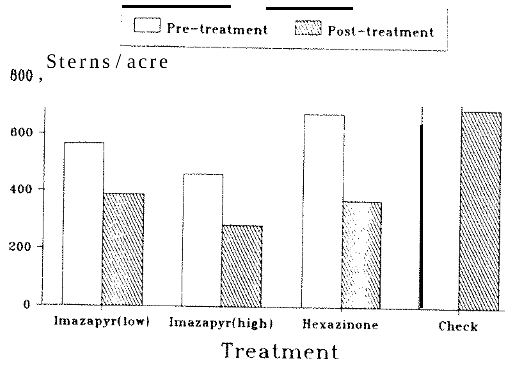

Figure 8. Pre- and post-treatment total hardwood stems/ac.

although these changes were not significantly different from zero (α = 0.10). Both rates of imazapyr produced significant (α = 0.10) reductions in total hardwood stem density (Fig. 8). The low rate reduced total hardwood stems from 566 to 389 stems/ac, while the high rate reduced total hardwood density from 460 to 283 stems/ac. A reduction of 301 stems/ac, from 672 to 371 stems/ac, was observed on the hexazinone plots, but this difference was not significant. Similarly, the observed reduction of 36 stems/ac on the check plots was not statistically significant.

Discussion

The observed difference in pine height growth between the two imazapyr treatments and the hexazinone and untreated check treatments indicates the presence of a significant pine height growth suppression effect attributable to the granular imazapyr. The absence of any difference in pine height growth rates between the untreated check and the hexazinone treatment may be attributed to one or a combination of several factors. Total hardwood densities did not decrease significantly from time one to time two on these two treatments, although the absolute decrease on the hexazinone plots was substantial (301 stems/ac). This indicates a high level of hardwood density variation within and between the plots treated with hexazinone. It is possible that this variation may have masked the true effectiveness of the hexazinone. The most probable cause for the lack of a pine height growth response is the relative insignificance of hardwood competition on pine growth during the stage of stand development in question. This is exacerbated by the relatively low initial hardwood densities present in the stand. It is quite possible that significant pine growth responses will become evident at some later stage of stand development. Support for this has recently been documented on the Auburn University Silvicultural Herbicide Cooperative's competition control studies (Zutter 1990) where hardwood competition is gradually exerting a greater impact on pine growth as opposed to herbaceous competition effects once the stand reaches age 5.

Conclusions

Utilization of granular Arsenal 5G and Pronone 10G to control competing hardwood vegetation at the beginning of the third growing season in a loblolly pine plantation was successful in reducing hardwood density at all tested rates. The imazapyr product significantly reduced the pine height growth in the year following treatment. The hexazinone product did not significantly enhance or reduce pine height growth compared to the untreated check. Our plans to continue monitoring these plots for several years may reveal longer-term effects on pine growth. At some point after installation of this test the decision was made by American Cyanamid not to commercially market Arsenal in the 5G formulation.

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COMPETING VEGETATION COMPOSITION AND DENSITY AFFECTS LOBLOLLY PINE PLANTATION GROWTH AND DEVELOPMENT [1]

Terry R. Clason [2]

Abstract. Altering overstory vegetation composition and density influenced growth and development of a loblolly pine (*Pinus taeda* L.) plantation. Hardwood suppression treatments applied age 7 indicated hardwood competition reduced pine growth through age 12 by 27 percent. By age 22, mean merchantable volume growth with and without suppression was 2,780 and 2,450 ft^3/ac. Although thinning treatments at age 12 and 17 had no effect on pine volume growth at age 22, sawtimber volume growth responses were detected. Unthinned sawtimber volume growth was 0.25 mbf (mbf= 1,000 board ft) per acre less than thinned sawtimber growth. Failure to alter overstory vegetation reduced merchantable and sawtimber volumes at age 22 by 800 ft^3/ac and 1.9 mbf/ac.

Introduction

Woody perennial vegetation restricts pine growth during the sapling and maturing stages of plantation development. Negative effects of hardwood brush and excessive pine stocking result in decreased volume yields and lower wood values.

A pine release study established in a 7-year-old loblolly pine (*Pinus taeda* L.) plantation demonstrated the competitive effect of hardwood brush (Clason 1984). Periodic pine growth between ages 7 and 12, and ages 12 and 17 was 29 and 45 percent less without release. During 10 years of growth, which encompassed sapling and maturing stages of development, hardwood brush reduced merchantable volume growth by 460 ft^3/ac.

Excessive pine stocking begins to influence plantation growth during the sapling stage of development (Hansbrough et al., 1964). Growth between ages 9 and 12 for an initial stocking density of 900 trees/ac (TPA) was 180 ft^3/ac less than 435 TPA. For the same spacing study, 900 and 435 TPA periodic growth from age 12 to age 17 averaged 1,960 and 2,190 ft^3/ac, respectively, differing by 230 ft^3 (Sprinz et al., 1980).

Since hardwood brush and excessive pine stocking reduce growth during similar stages of plantation development, a potential for an interactive relationship exists. Therefore, a competition management study was established in a 7-year-old loblolly pine plantation to determine the interactive impact of interspecific and intraspecific competition.

Methods And Procedures

The study area was a variably stocked loblolly pine plantation planted in 1964 at a density of 900 TPA. Predominant soil type was a

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McLaurin loamy fine sand with an estimated age 25 site index of 65 ft. Pine density at age 7 averaged 400 TPA. The predominant overstory was loblolly pine, sweetgum (Liquidambar sytraciflua L.), and water oak (Quercus nigra L.). Hardwood brush was heavy to moderate, averaging 400 stems and 4 ft^2/ac.

The interactive competitiveness of hardwood and pine stocking was evaluated with the following treatments: (1) hardwood suppression and early thinning (HSET); (2) hardwood suppression (HS); (3) no hardwood suppression and early thinning (NHSET); and (4) no hardwood suppression (NHS). Treatments were assigned to 0.20-ac plots containing a 0.125-ac measurement area and replicated four times in a completely random design.

Pine density on all plots was adjusted to 350 TPA at age 7. All hardwoods on the HSET and HS plots were cut and stump surfaces sprayed with a 1:4 mixture of 2,4,5-T LVE and diesel fuel. An early commercial thinning reduced pine density at age 12 to 200 TPA on the HSET and NHSET. Thinning at age 17 reduced pine density on all plots to 150 TPA. All plots were prescribed burned at ages 10, 12, 15, 17, 20, and 22.

Individual tree growth data were collected at ages 7, 12, 17, and 22. Outside bark and double bark thickness were measured at dbh to the nearest 0.01 inch. Total height and height to live. crown measurements were taken to the nearest 0.1 ft. All hardwood vegetation on a measurement plot was tallied and dbh and height measured on all stems greater than 4.5-ft tall. Merchantable volume data were computed to a 3-inch inside bark diameter using a local volume equation (Clason and Cao, 1986). Board feet (Doyle scale) were calulated from sawtimber cubic-foot volume with a conversion factor reported by Williams and Hopkins (1968). Data were analyzed with a standard ANOVA at a 0.05-level of probability, using treatment plots as the experimental unit. Individual mean differences were tested orthogonally by comparing HSET and HS vs NHSET and NHS; HSET vs. HS; and NHSET vs. NBS.

Results And Discussion

Age 7 growth attributes did not differ among treatments. Stand density, dbh, basal area, height, and merchantable volume averaged 336 TPA, 3.5 inches, 25 ft^2/ac, 20 ft, and 200 ft^3/ac, respectively (Table 1). Between ages 7 and 12, hardwood basal area growth on NHSET and NSH treatments, which averaged 11 and 9 ft^2/ac, respectively, had no detectable effect on pine mortality rate. Mean pine dbh, basal area, and volume growth without hardwood suppression were 0.3 inches, 11 ft^2/ac, and 250 ft^3/ac less than with hardwood suppression.

Residual pine stocking densities at age 12 were 188, 186, ,296, and 278 TPA for HSET, NHSET, HS, and NHS treatments, respectively; and respective volumes were 1,040, 850, 1,250, and 980 ft^3/ac. HSET and NHSET thinning yields did not differ, averaging 270 and 230 ft^3/ac. Growth losses at age 17 were attributed to hardwood brush, but not to differing pine stocking densities. Hardwood basal area growth averaged 7 ft^2/ac on the NHSET and NBS treatments. Mean pine dbh, basal area, and volume growth were 0.2

Table 1. Treatment growth attributes for ages 7, 12, 17, and 22.

Treatment	Density	Dbh	Basal area Pine	Basal area Hardwood	Merchantable volume	Sawtimber volume
	TPA	inch	---- ft²/ac ----		-- ft³/ac --	mbf/ac
			Age 7			
HSET	360	3.4	25	0	190	0
NHSET	338	3.6	26	4	220	0
HS	332	3.7	26	0	210	0
NHS	314	3.3	21	4	170	0
			Age 12			
HSET	312	5.9	61	0	1,310	30
NHSET	298	6.4	69	14	1,070	40
HS	296			0	1,250	0
NHS	278	5.8	55	13	980	70
			Age 12 harvest			
HSET	124	5.0	18	0	270	0
NHSET	112	4.7	15	0	230	0
			Age 12 residual			
HSET	188	7.2	54	0	1,040	30
NHSET	186	6.6	46	14	850	40
HS	284	8.1	105	0	2,230	880
NHS	236	7.6	76	20	1,530	560
			Age 17			
HSET	188	8.7	86	0	1,900	1,120
NHSET	186	7.8	64	21	1,310	410
HS	284	8.1	105	0	2,230	880
NHS	236	7.6	76	20	1,530	560
			Age 17 harvest			
HSET	42	6.6	14	0	270	0
NHSET	64	6.3	15	0	280	50
HS	132	6.8	34	0	630	0
NHS	84	6.0	17	0	290	0
			Age 17 residual			
HSET	146	9.4	72	0	1,630	1,120
NHSET	138	8.3	53	21	1,100	360
HS	152	9.2	71	0	1,590	880
NHS	152	8.4	59	20	1,240	560
			Age 22			
HSET	146	11.1	100	1	2,490	4,290
NHSET	138	9.7	75	33	1,760	1,960
HS	152	10.6	94	1	2,300	3,400
NHS	148	9.9	81	34	1,930	2,410

inches, 14 ft^2/ac, and 420 ft^3/ac less, respectively, than were the HSET and HS treatments. Total volume growth through age 17 for thinned and unthinned treatments averaged 1,650 and 1,690 ft^3/ac, respectively.

Thinning yields at age 17 differed among treatments, with the HS treatment harvests exceeding the HSET, NHSET, and NHS treatments by 360, 350, and 340 ft^3/ac, respectively. Hardwood competition had a significant effect on age 17 residual stand attributes, while early thinning had no detectable effect. Hardwood brush reduced NHSET and NHS residual pine dbh, basal area, and volume by 0.9 inches, 15 ft^2/ac, and 460 ft^3/ac, respectively (Table 1).

Pine basal area and volume growth between ages 17 and 22 varied among treatments. HSET, NHSET, HS, and NHS basal area growth averaged 28, 22, 23, and 22 ft^2/ac, respecively, and respective volume growth averaged 860, 660, 710, and 690 ft^3/ac. Periodic growth differences at age 22 suggest that overstory hardwood and pine can interactively impact the maturing stage of plantation development.

Total volume yields at age 22 with and without hardwood suppression differed significantly, averaging 2,780 and 2,050 ft^3/ac. Although thinning at age 12 had no effect on total volume yields (Table 1), early thinning increased sawtimber volumes at age 22 by 0.25 mbf/ac. After 15 years, NHS total and sawt imber volumes were 800 ft^3/ac, and 1.9 mbf/ac less than the HSET volumes.

The competitive dynamics of hardwood overstory on loblolly pine plantation development were demonstrated during the 15-year growth period. Failure to suppress hardwood competition resulted in a mean annual volume growth loss of 52 ft^3/ac. In addition, significant volume growth losses were detected during each 5-year measurement period. Maximum periodic growth loss, 410 ft^3/ac, occurred between ages 12 and 17. Plantation value was lower at age 22 because hardwood competition reduced sawtimber volume by 1.67 mbf/ac.

The impact of intraspecfic competition on plantation development was not readily discernable. Residual stocking densities may have masked volume growth differences between thinning treatments. HSET and HS volume growth between ages 12 and 17, which averaged 860 and 980 ft^3/ac, was similar to that reported by Sprinz et al. (1980) for 200 and 300 TPA on old-field sites. Although early thinning did not improve volume growth, it did provide an early source of income. In fact, the impact of pine denisty appeared to be more economic than biological because HS sawtimber volume at age 22 was 0.8 mbf/ac less than HSET.

Conclusions

Growing space availability had a significant impact on loblolly pine growth and development. Failure to manage interspecific and intraspecific competition reduced wood yields and lowered wood values. When residual pine stocking densities average 350 TPA, hardwood suppression at age 7 combined with early thinning will enhance volume yields and improve wood values.

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